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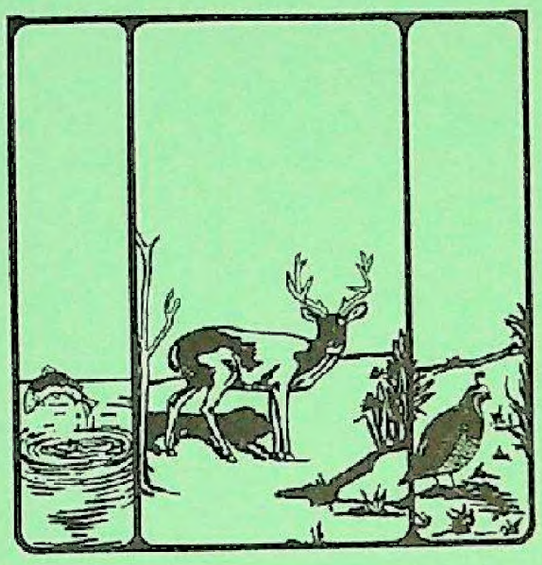

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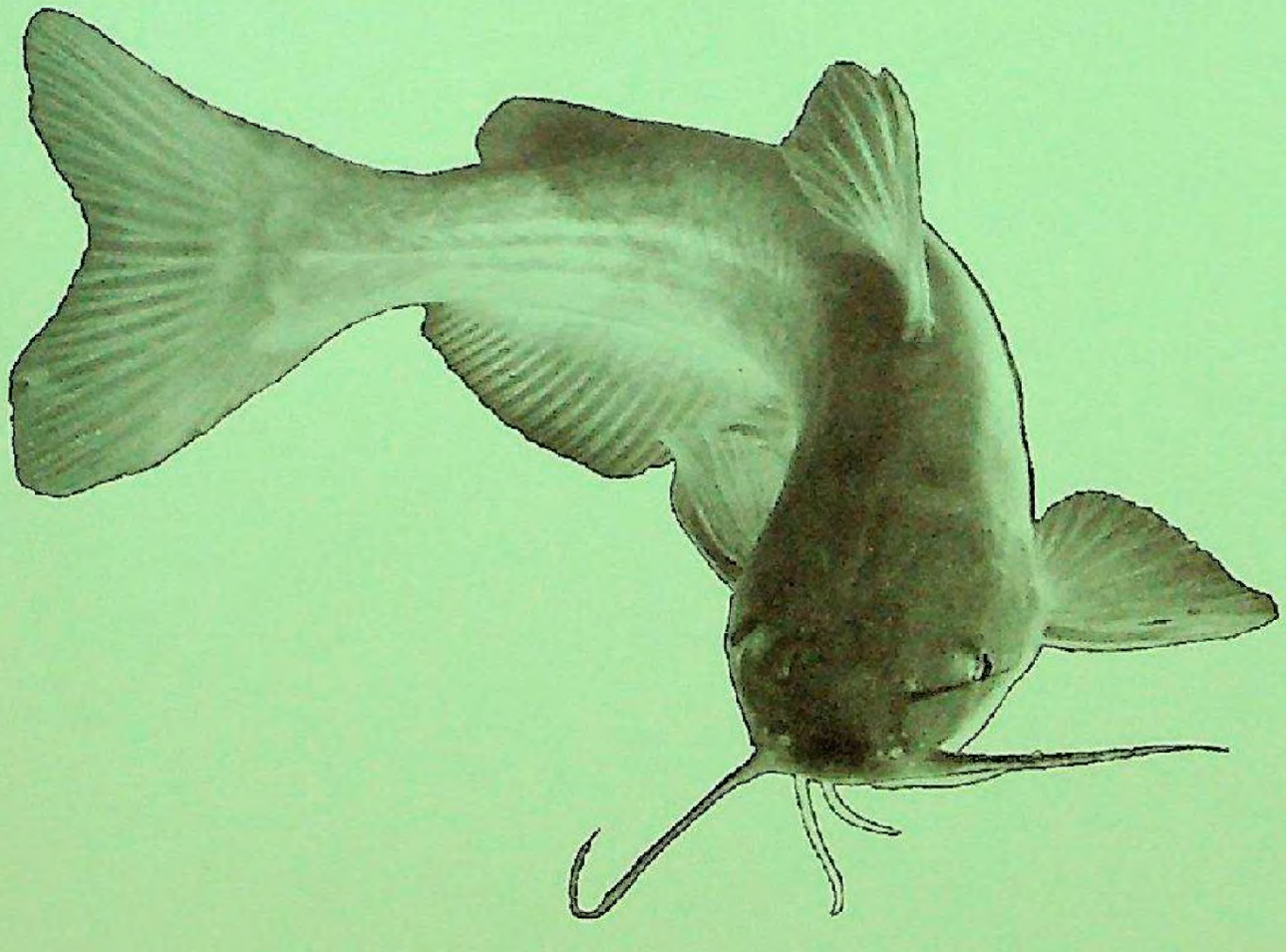

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Please direct correspondence to:

David W. Kohlhorst or James J. Orsi
Co-Editors-in-Chief
California Fish and Game
4001 North Wilson Way
Stockton, California 95205-2486
e-mail: dkohlhor@delta.dfg.ca.gov
jorsi@delta.dfg.ca.gov

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White Catfish, *Ameiurus catus*
Photograph by Raymond G. Schaffter, August 1997

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MORTALITY RATES OF WHITE CATFISH IN CALIFORNIA'S SACRAMENTO-SAN JOAQUIN DELTA

RAYMOND G. SCHAFFTER and DAVID W. KOHLHORST
California Department of Fish and Game
4001 North Wilson Way
Stockton, California 95205-2486

White catfish, *Ameiurus catus*, were tagged at 10 locations in the Sacramento-San Joaquin Delta in fall and early winter from 1978 to 1980. Estimated mean total annual mortality rates of fish ≥240 mm fork length ranged from 0.31 in Beaver and Disappointment sloughs to 0.67 in the San Joaquin River at Mossdale. Estimated average annual exploitation rates of white catfish ≥240 mm fork length varied from 0.14-0.18 in the northern delta to 0.25 in the San Joaquin River. Exploitation rate increased with fish size. In comparison with an earlier tagging study, mean total mortality decreased from 0.46-0.57 in 1953-1954 to 0.36-0.44 in 1978-1980, largely because of a decrease in fishing mortality.

INTRODUCTION

Environmental Setting

The Sacramento-San Joaquin Delta is formed by the branching distributaries of the Sacramento, San Joaquin and Mokelumne rivers (Fig. 1). Historically, most of this area was tidal marsh, but from the 1870s to 1910 levees were built along all major channels. Presently, about 1,125 km of waterways exist, ranging in channel width from 30 to 1,500 m; depths are typically < 13 m (Kelley 1966).

Before upstream water development began, an average of 34 million cubic dekameters of outflow passed annually through delta channels into San Francisco Bay (Nichols et al. 1986). This outflow was highly seasonal; about 70% occurred from January through May. Agricultural and municipal consumption in the Sacramento-San Joaquin drainage has reduced delta inflow by nearly 40% and two major water projects pumping from the southwest delta now export about 24% of historical inflow. Most exported water is drawn across the delta from the Sacramento River through north delta channels and the lower reaches of Old and Middle rivers. During summer periods of high water diversion, the combination of large-scale water development in the San Joaquin River drainage and export of Sacramento River water has increased downstream water velocity in north delta channels, reversed the flow direction in Old and Middle rivers, and reduced downstream velocities in the lower San Joaquin River from Mossdale to west of Stockton.

White catfish

White catfish, *Ameiurus catus*, first released into the Sacramento-San Joaquin Delta in 1874, are one of many successful introductions of fishes to California from

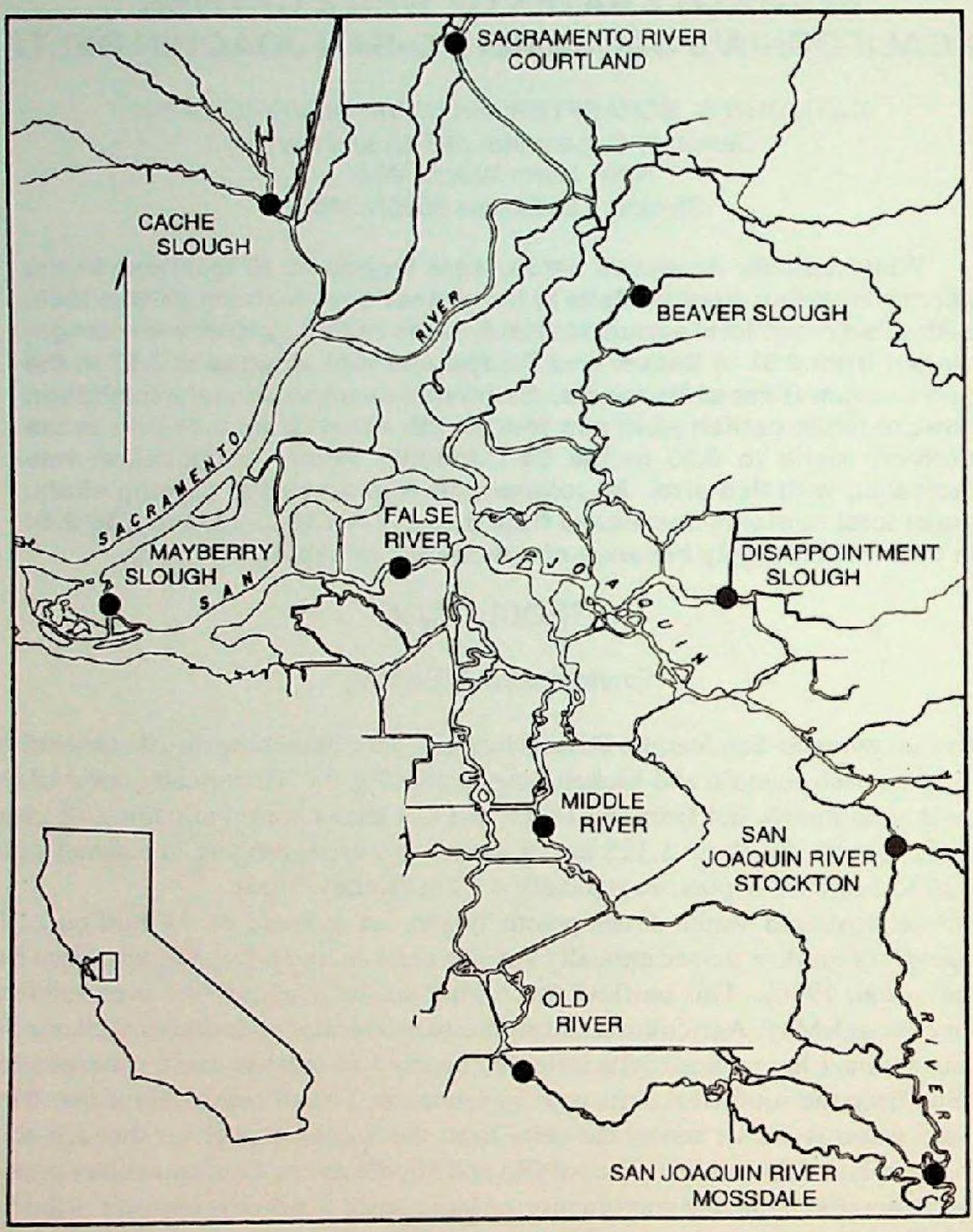

Figure 1. White catfish tagging locations in the Sacramento-San Joaquin Delta, 1978-1980.

the eastern United States (Shebley 1917). Between 1916 and 1952, the commercial harvest of white catfish from the delta ranged from 81,000 to 460,000 kg (Skinner[1] 1962). In the late 1940s and early 1950s, a decline in delta commercial and sport

[1] Skinner, J.E. 1962. An historical review of the fish and wildlife resources of the San Francisco Bay area. California Department of Fish and Game, Water Projects Branch Report No. 1.

catches led to the general belief that the fishery was depleted (Pelgen 1954). This resulted in legislative closure of the commercial fishery in 1953 and the initiation of the first delta catfish investigations. Immediately following the commercial fishery closure, estimated total annual mortality ranged from 0.50 for fish <189 mm fork length (FL) to 0.57 for fish >215 mm FL. Larger fish experienced greater mortality because vulnerability to angling increased with fish size (Borgeson and McCammon 1967).

Many of the hydrological changes in the delta associated with increased water development have occurred since the early 1950s. Also, angling effort has probably changed with human population growth and changes in leisure activities. Our report provides estimates of white catfish mortality rates in the Sacramento-San Joaquin Delta under these more recent conditions.

METHODS

Sampling

White catfish were captured in 107-cm diameter hoop nets constructed of 5-cm stretch-mesh nylon webbing and set at 10 locations in the Sacramento-San Joaquin Delta during fall and early winter 1978-1980 (Fig. 1). Fish were tagged at this time of year to minimize potential tagging mortality associated with high water temperatures (Pelgen and McCammon 1955) and to sample fish that had completed their annual growth for a companion growth study (Schaffter 1997). Water temperature was recorded when hoop nets were set and retrieved. Captured white catfish were measured to the nearest millimeter FL and healthy fish ≥180 mm were tagged below the dorsal fin with a disk-dangler tag (Chadwick 1966). At least 1,000 white catfish at each location each year were tagged. At locations where fish were most abundant or easy to catch, up to 3,000 were tagged annually. To measure angler response (the fraction of tagged fish caught by anglers that is reported to the Department of Fish and Game), a $10-reward tag was applied to every 10th fish of the first 1,000 tagged at each site each year. During 1979 and 1980, tag number, fork length, security of tag attachment, and tag induced irritation were recorded for all previously tagged fish that were recaptured.

All tag returns by anglers were acknowledged with a commendation card. If recovery information was incomplete, a postpaid card was sent with the commendation card requesting missing information.

Analysis

To evaluate the size dependency of mortality rates, we pooled all recoveries into 20-mm size classes from 180 through 279 mm FL at the time of tagging. All returns from white catfish ≥280 mm at tagging were grouped together.

Minimal geographic dispersion of white catfish recaptured during subsequent tagging indicated that tagged fish were not randomly mixing throughout the delta. Of 838 hoop-net recaptures of white catfish tagged in previous years, only 35 (4%) were

taken at a location other than the original tagging site. Hence, we developed site-specific mortality estimates and pooled sites only when site tag-return matrices were not significantly different ($P > 0.05$) based on chi-square contingency tests of row, column, and block subtotals (Brownie et al. 1985).

We estimated annual survival rate (S), tag recovery rate, and their 95% confidence intervals using the Maximum Likelihood (ML) method (Brownie et al. 1985). The ML method fits tag return data to a series of models representing various assumptions about annual survival and recovery rates. Chi-square goodness-of-fit tests based on observed and expected tag recovery matrices and likelihood ratio tests between models (also distributed approximately as chi-square) were used to select the simplest model that adequately fit the data (Brownie et al. 1985). Results were considered significant if $P < 0.05$.

Maximum-likelihood estimates of survival rate and tag recovery rate were used to estimate mortality rates. Total annual mortality rate (A) was calculated as 1 - survival rate (S). Annual rate of exploitation (u) was calculated as annual tag recovery rate divided by response rate (r), where:

$$r = (R_{NR}M_{10})/(R_{10}M_{NR})$$

and M_{NR} = number of non-reward tags released at the same time as reward tags,
M_{10} = number of reward tags released,
R_{NR} = number of non-reward tags returned the 1st yr, and
R_{10} = number of reward tags returned the 1st yr.

We assumed anglers returned all $10-reward tags they recovered. Annual natural mortality rate (v) was estimated by subtracting exploitation rate from total mortality rate.

We tested the fit of four different ML models to the white catfish tag return data. The most general model, Model 3, assumes constant annual survival and tag recovery rates. Model 2 assumes constant survival, but year-specific tag recovery rates. Model 1 assumes both survival and tag recovery rates are year-specific and is a bias-adjusted version of the model developed by Seber (1970) and Robson and Youngs[2] (1971). Model 0 also assumes survival and recovery rates are year-specific, but allows 1st-yr recovery rates to be different than recovery rates for previously tagged individuals. Hence, situations in which either tag reporting rates or exploitation rates differ between 1st- and later-yr returns fit model 0. However, if exploitation rates rather than recovery rates differ between newly tagged individuals and those that have been at large for $\geq$ 1yr, the ML survival rate estimates from Model 0 are biased (Brownie et al. 1985).

In Cache and Mayberry sloughs and the Sacramento River, where capture and handling mortality was high in 1979 (see Results), we employed Model 2 to estimate average survival for the 2-yr period following 1978 tagging by using only 1978 and 1980 data and pooling return data for 2-yr periods. In these cases, we computed annual survival for the 1978 release group as the square root of the 2-yr survival rate estimate.

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[2] Robson, D.S. and W.D. Youngs. 1971. Statistical analysis of reported tag-recaptures in the harvest from an exploited population. BU-369-M, Biometrics Unit, Cornell University, Ithaca, New York, USA.

We estimated 1978 and 1980 tag recovery rates as the fraction of tags recovered during the year following tagging, and confidence limits for these estimates were derived from binomial variance estimators (Snedecor and Cochran 1968).

We compared mortality rates estimated from 1978-1980 and 1953-1954 tagging by using a Student's t-test for equality of slopes (Z) of the linear regression of $\log_e$(tag returns) on year for the first 5 yr after tagging. In the 1953-1954 study, Borgeson and McCammon (1967) pooled return data for tagging years and locations, stratified by three length intervals: 165-189 mm, 190-215 mm, and >215 mm. For the comparison, we similarly pooled and stratified returns only from the four 1978-1980 tagging sites (Mayberry, Cache, and Disappointment sloughs and Old River) that were also used in 1953-1954.

RESULTS

Over 62,000 white catfish were tagged during the 3 yr of the study (Table 1). Over 70% of these were tagged in the south and east delta where white catfish were easiest to catch and, presumably, most abundant.

Through the 8th recovery yr, anglers returned 727 of 2,990 reward tags and 7,500 of 59,400 non-reward tags. Estimated angler response rates were 0.55, 0.56, and 0.40 for the years following the 1978, 1979, and 1980 tagging.

The ML model that best fit white catfish tag return data varied with fish size. Model 0 provided the only statistically acceptable fit to the tag return data for fish <220 mm FL from the pooled tagging locations (other than those with high 1979 tagging mortality) because 1st-yr recovery rates were lower than for previously tagged fish (Table 2). These smaller white catfish were more vulnerable to anglers after the 1st yr due to growth, as demonstrated by consistent increases in exploitation with fish size (Table 2). As the difference in 1st-yr recovery of tags from smaller fish was not due to reporting differences, Model 0 yielded biased survival estimates. Models 1 and 2 were applicable to larger fish.

We estimated site-specific mortality rates only for white catfish ≥240 mm FL. This was the minimum size that provided an adequate sample at each location, although it still included fish 240-259 mm FL that were not fully recruited to the fishery.

Tag returns for white catfish ≥ 240 mm FL from all tagging locations except Old and Middle rivers fit Model 2, implying constant mortality rate and year-specific recovery rates (Table 3). Tag return matrices from Beaver and Disappointment sloughs and False River were not statistically different from each other and were combined to estimate mortality rates. Tag-return matrices from the San Joaquin River sites near Stockton and Mossdale were statistically different from each other and all other tagging sites.

Tag returns from Old and Middle rivers fit Model 1, implying both year-specific total mortality and recovery rates. The statistical similarity of tag-return matrices at these two locations allowed them to be combined to estimate mortality rates.

We found angler returns from Mayberry and Cache sloughs and the Sacramento

Table 1. Number of white catfish tagged and catch per hoop-net-h (CPNH) in the Sacramento-San Joaquin Delta from 1978 to 1980.

Location	1978 Tagged	1978 CPNH	1979 Tagged	1979 CPNH	1980 Tagged	1980 CPNH	Total Tagged	Mean CPNH
Cache Slough	1,382	0.61	1,105	0.22	1,293	0.33	3,780	0.35
Sacramento River at Courtland	1,298	0.52	1,087	0.33	1,300	1.32	3,685	0.72
Beaver Slough	1,273	0.38	1,273	0.29	1,422	0.45	3,968	0.39
False River	1,100	0.34	997	0.15	1,097	0.25	3,194	0.25
Disappointment Slough	3,025	2.07	2,999	0.68	2,870	1.61	8,894	1.30
San Joaquin River at Stockton	3,000	1.57	3,001	0.70	2,993	0.59	8,994	0.90
San Joaquin River at Mossdale	3,004	2.80	2,997	3.19	2,995	2.73	8,996	2.81
Old River	2,945	1.16	2,923	2.09	2,976	1.12	8,844	1.45
Middle River	2,750	0.73	2,681	0.55	2,998	0.56	8,429	0.59
Mayberry Slough	1,106	0.16	1,208	0.22	1,292	0.28	3,606	0.22
Total/Mean	20,883	0.76	20,271	0.64	21,236	0.69	62,390	0.68

River much lower than expected following 1979 tagging and suspect that this was caused by high tagging mortality. Normally, <4% of white catfish captured in hoop nets were in such poor condition that they were not tagged. However, in September and early October 1979 in Cache and Mayberry sloughs and the Sacramento River, 23% of the captured catfish were dead, moribund, or unfit for tagging because of severe epidermal lesions. Water temperatures at these sites exceeded 21°C; at other locations and times, water temperatures were usually 7-18°C. Our belief that tagging mortality was abnormally high, in spite of our excluding obviously stressed fish, was supported by fish <240 mm FL from these three sites having negative estimated total

Table 2. Maximum Likelihood estimates (Brownie et al. 1985) of total mortality rate (A), recovery rate, exploitation rate (u), and natural mortality rate (v) for the pooled sample of white catfish from Beaver and Disappointment sloughs; the San Joaquin River near Stockton and Mossdale; and Old, False, and Middle rivers stratified by 20-mm length intervals.

Fork length	Year	A	95% Confidence interval	Recovery rate	95% Confidence interval	u	v	Model
199 mm	1978	0.36	0.22-0.50	0.05	0.04-0.06	0.09	0.27	0
	1979	0.32	0.19-0.45	0.03	0.02-0.04	0.06	0.26	
	1980			0.02	0.01-0.03	0.06		
	Mean	0.34	0.25-0.43	0.04	0.03-0.05	0.07	0.27	
200-219 mm	1978	0.38	0.27-0.49	0.07	0.06-0.08	0.12	0.26	0
	1979	0.29	0.16-0.42	0.05	0.04-0.06	0.08	0.22	
	1980			0.03	0.02-0.04	0.06		
	Mean	0.33	0.25-0.42	0.05	0.04-0.06	0.09	0.25	
220-239 mm	1978	0.33		0.09	0.08-0.10	0.16	0.17	2
	1979	0.33		0.06	0.05-0.07	0.11	0.22	
	1980			0.04	0.03-0.05	0.10		
	Mean	0.33	0.27-0.39	0.06	0.05-0.07	0.12	0.21	
240-259 mm	1978	0.51	0.42-0.60	0.12	0.10-0.13	0.21	0.30	1
	1979	0.27	0.12-0.42	0.07	0.06-0.08	0.12	0.15	
	1980			0.05	0.04-0.06	0.13		
	Mean	0.39	0.32-0.46	0.08	0.07-0.09	0.15	0.24	
260-279 mm	1978	0.52		0.14	0.12-0.17	0.26	0.26	2
	1979	0.52		0.08	0.05-0.10	0.13	0.39	
	1980			0.07	0.05-0.08	0.16		
	Mean	0.52	0.44-0.61	0.10	0.08-0.11	0.19	0.33	
≥280	1978	0.46		0.16	0.12-0.19	0.29	0.17	2
	1979	0.46		0.08	0.06-0.10	0.14	0.32	
	1980			0.07	0.06-0.09	0.18		
	Mean	0.46	0.36-0.57	0.10	0.06-0.12	0.20	0.26	

annual mortality rates following 1978 tagging due to disproportionately low returns of fish tagged in 1979. Because of this bias, we discarded returns from 1979 tagging and modified our analysis for these sites as described in Methods. The resultant three tag-return matrices from Cache and Mayberry sloughs and the Sacramento River were not significantly different and were pooled for a single survival estimate.

Mortality rates for fish ≥240 mm FL varied widely in different areas of the delta (Table 3). Estimated average total annual mortality rates ranged from 0.31 in Beaver and Disappointment sloughs and False River to 0.67 in the San Joaquin River near Mossdale. Estimated mean exploitation rate varied from 0.14 at Beaver and Disappointment sloughs and False River to 0.25 in the San Joaquin River at Mossdale.

Table 3. Annual total mortality rate (A), recovery rate, exploitation rate (u), and natural mortality rate (v) of white catfish ≥240 mm FL in the Sacramento-San Joaquin Delta. Locations are combined based on statistical similarity of their tag-recovery matrices and are arranged in order of increasing total mortality.

Location	Year	A	95% Confidence interval	Recovery rate	95% Confidence interval	u	v	Model
Beaver Slough	1978	0.31		0.11	0.10-0.13	0.20	0.11	2
Disappointment	1979	0.31		0.06	0.05-0.07	0.11	0.20	
Slough	1980			0.05	0.04-0.06	0.13		
False River	Mean	0.31	0.22-0.40	0.07	0.06-0.08	0.14	0.17	
Cache Slough[a]	1978	0.34		0.11	0.09-0.13	0.20	0.14	2
Mayberry Slough	1979	0.34						
Sacramento River	1980			0.06	0.04-0.09	0.15		
at Courtland	Mean	0.34	0.25-0.44	0.09	0.08-0.10	0.18	0.16	
Old River	1978	0.62	0.51-0.71	0.11	0.09-0.13	0.20	0.42	1
Middle River	1979	0.28	0.11-0.46	0.07	0.06-0.08	0.13	0.15	
	1980			0.05	0.04-0.06	0.13		
	Mean	0.44	0.35-0.53	0.09	0.08-0.10	0.16	0.28	
San Joaquin River	1978	0.64		0.14	0.11-0.18	0.26	0.38	2
at Stockton	1979	0.64		0.12	0.09-0.14	0.21	0.43	
	1980			0.10	0.07-0.13	0.26		
	Mean	0.64	0.54-0.74	0.12	0.10-0.14	0.24	0.40	
San Joaquin River	1978	0.67		0.21	0.17-0.25	0.38	0.29	2
at Mossdale	1979	0.67		0.10	0.07-0.14	0.18	0.49	
	1980			0.08	0.04-0.12	0.19		
	Mean	0.67	0.54-0.82	0.13	0.11-0.15	0.25	0.42	

[a] Survival estimated from square root of the 1978-1980 survival based only on 1978 and 1980 returns; see text.

Similarly, estimated average natural mortality rate was lowest at the six tagging locations in the north half of the delta (0.16-0.17) and highest at the four sites in the south half of the delta, especially the two San Joaquin River tagging locations (0.40-0.42). Hence, both higher fishing and natural mortality apparently contributed to the high total mortality in the San Joaquin River.

The locations that fit Model 1 with year-specific total mortality rates (Old and Middle rivers) exhibited a large annual difference in estimated total mortality, decreasing from 0.62 in 1978 to 0.28 in 1979.

Total mortality for large white catfish decreased from 1953-1954 to 1978-1980 based on comparisons of regression slopes of $\log_e$(tag returns) on year (Table 4). Decreases in total mortality from 0.46 to 0.36 for fish 190-215 mm FL and from 0.57

to 0.44 for fish ≥216 mm were significant (t = -6.95 and t = -7.98, each with df = 6, P <0.001). Slopes for white catfish ≤189 mm were not significantly different(t = 1.53, df = 6, P >0.10).

DISCUSSION

To obtain unbiased estimates of mortality and survival from a tagging study relying on angler reporting of tagged fish, the following conditions must be met (Ricker 1975):

1) Mortality does not differ between tagged and untagged fish.
2) Both tagged and untagged fish are equally vulnerable to the fishery.
3) Tags are not shed.
4) All tags are recognized and reported on recovery or the mark recovery rates are known.
5) Marked fish mix randomly with the untagged fish in the population.

Returns from striped bass up to 17 yr after tagging (Chadwick 1963; California Department of Fish and Game, unpubl. data) and from white catfish up to 14 yr after tagging (California Department of Fish and Game, unpubl. data) suggest that disk-dangler tags cause little or no long-term mortality. The extraneous mortality at three tagging locations in 1979 occurred shortly after tagging, as indicated by low 1st-yr returns, and was confined to groups of fish that were obviously in poor condition

Table 4. Comparison of pooled 1st- through 5th-yr tag returns and estimated total annual mortality rates (A) for fish tagged at Mayberry, Cache, and Disappointment sloughs and Middle River for 1953-1954 (Borgeson and McCammon 1967) and 1978-1980. $A = 1-e^{-Z}$, where Z is the slope of the regression of $\log_e$(tag returns) on year. Data are grouped into size intervals reported by Borgeson and McCammon. The Student's t-test and associated probabilities reflect a test between slopes of the regression lines (H_0: $b_1 - b_2 = 0$) within each size group between 1953-1954 and 1978-1980 tagging periods.

	Length interval					
	189 mm		190-215 mm		≥215 mm	
	1953-1954	1978-1980	1953-1954	1978-1980	1953-1954	1978-1980
Total tagged	913	3,721	1,590	10,028	985	11,038
1st-yr returns	84	110	232	425	208	759
2nd-yr returns	67	110	148	305	75	417
3rd-yr returns	48	41	70	188	37	243
4th-yr returns	36	49	41	123	14	127
5th-yr returns	22	21	20	83	7	72
Average total annual mortality	0.28	0.32	0.46	0.36	0.57	0.44
r^2	0.98	0.86	1.00	0.99	1.00	1.00
Slope comparisons	t = 1.567, df = 6, P >0.1		t = -6.951, df = 6, P <0.001		t = -7.98; df = 6, P <0.001	

at tagging due to confinement and handling stress at high water temperatures. Mortality rates calculated only from 1978 and 1980 releases at these locations were consistent with rates at the other locations in the north and central delta.

Tagging probably reduced exploitation of small white catfish by decreasing growth, thus prolonging their time in less vulnerable size classes. Comparison of the annual growth increment calculated from aging untagged fish (Schaffter 1997) with average annual growth of tagged fish, computed from size at tagging and recaptured in the hoop nets, suggests that tagging reduced growth rate by about 40%. Chadwick (1963) found recaptured tagged striped bass were more likely to be smaller at a given age than comparable untagged fish and attributed this to slower growth caused by irritation and soreness around the tag attachment wires on 40-63% of the tagged striped bass. In the present study, 26% of tagged white catfish recaptured in hoop nets 1 or 2 yr after tagging exhibited lesions at the tag attachment wires. By using only large (≥240 mm FL) white catfish for area-specific exploitation and mortality estimates, we minimized bias caused by reduced growth of tagged fish.

Shedding of disk-dangler tags by white catfish has not been evaluated with double-tagging experiments in the wild, but Pelgen (1954) reported disk-dangler-tagged white catfish held in a pond for 1 yr exhibited no tag shedding. During our study, we recaptured 838 tagged white catfish after they had been at liberty up to 2 yr. Nine of these were retagged because one of the two attachment wires had migrated vertically through the dorsal body surface and two were scarred when captured, suggesting a tag had been shed.

Striped bass retain disk-dangler tags well. Chadwick (1963) reported a low incidence of healed scars and broken tag wires on striped bass as evidence of a low (but unknown) rate of shedding. Smith (1978) found that striped bass shed disk-dangler tags at a 4.9% annual rate for the first 4 yr following tagging; the shedding rate in subsequent years was even lower. Chadwick (1966) reported that disc-dangler tags gave better results on slow-moving fish such as catfish as opposed to pelagic fish such as striped bass.

The assumption of 100% response for $10-reward tags is probably an overestimate, as $10 may not be enough to make all anglers report their catch of tagged fish. The error introduced by <100% return of reward tags causes exploitation rate to be underestimated and natural mortality rate to be overestimated, but does not affect estimates of total mortality rate. The decline in return of non-reward tags from 56% the 1st yr to 40% following the 3rd yr of tagging is reasonable because many catfish anglers fishing near release sites probably became accustomed to catching tagged catfish. A similar decline in response rates over time has been noted for tagged striped bass in the delta (Stevens et al. 1985).

While tagged fish did not randomly mix throughout the delta and, in fact, may not have mixed randomly near the release sites, random distribution of angling effort may have largely compensated for any lack of mixing of tagged fish. The narrow range of mean exploitation estimates (14-25%) for fish ≥240 mm among tagging locations (Table 3) supports the randomness of angler effort. If anglers were avoiding or targeting tagged fish near release sites, a wider range of values might be expected.

Estimated total mortality for white catfish ≥190 mm decreased between 1953-1954 and 1978-1980, based on comparison of slopes of the regression of $\log_e$(tag returns) on return year. Comparison of the 33% exploitation rate of fish ≥216 mm in 1953-1954 (Borgeson and McCammon 1967) with the 14-18% exploitation rates for fish ≥240 mm at common sites during 1978-1980 suggests exploitation rate also has decreased. The actual decrease in exploitation is probably greater than this because of the size dependence of fishing mortality and the larger fish used for the 1978-1980 estimates. Natural mortality was estimated to be 24% in 1953-1954 compared to 16-28% in 1979-1980, suggesting that the decrease in total mortality over this time is due mostly to reduced fishing mortality.

High exploitation and natural mortality rates at both San Joaquin River tagging locations is associated with high abundance at these sites (Table 1) and the generally young age distribution and small size of fish in the south and central delta (Schaffter 1997). This suggests that high mortality and recruitment combine to maintain a San Joaquin River population dominated by young fish. Large populations, such as those in the San Joaquin River, may attract anglers and result in increased fishing mortality. The reason(s) for elevated natural mortality are not known.

The decline in the delta white catfish exploitation rate between 1953-1954 and 1978-1980 may be due to a decrease in angler effort related to (i) reduced dependency on sport-caught fish as food, (ii) decline in angler esteem for catfish as a targeted sport fish, and (iii) decrease in delta shore-fishing opportunity because of increased posting and trespass enforcement along levees bordering private land. We lack data to evaluate these hypotheses.

Although an exploitation rate as high as 38% was estimated for white catfish ≥240 mm in the San Joaquin River at Mossdale in 1978, exploitation rates at most delta locations were on the order of 14-18%. These rates can be compared to the exploitation rates of 5-10% for white catfish in Clear Lake, California (McCammon and Seeley 1961) and 19% for Folsom Lake, California (Rawstron 1967). White catfish in these lakes were considered to be under-exploited and the same appears true for the delta population.

Based partly on the findings of this study, the California Department of Fish and Game in 1987 recommended to the Fish and Game Commission that the statewide 20-fish limit for white and channel, *Ictalurus punctatus*, catfish be removed. This change was adopted effective 1 March 1988.

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T. Taylor and the junior author designed the tagging study and with B. Collins, J. White, and J. Salada tagged most of the fish. D. Ramczyk and T. Morefield tallied angler tag returns and generated commendation cards and rewards. D. Stevens provided analytical and editorial suggestions. This study was performed as part of Dingell-Johnson Project California F-9-R, "A Study of Sturgeon, Striped Bass, and Resident Fishes" and Sport Fish Restoration Act Project F-51-R, Subproject VIII, "Sacramento-San Joaquin Delta Sport Fish Management".

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GROWTH OF WHITE CATFISH IN CALIFORNIA'S SACRAMENTO-SAN JOAQUIN DELTA

RAYMOND G. SCHAFFTER
California Department of Fish and Game
4001 North Wilson Way
Stockton, California 95205-2486

California's Sacramento-San Joaquin Delta is inhabited by one of the slowest growing populations of white catfish, *Ameiurus catus*, yet reported. White catfish in the south and central delta grow more slowly than fish in the north and west delta. At age 8, white catfish in the south and central delta reach only 253 mm fork length; fish from the north and west delta are 284 mm long at the same age. After age 4, males grow faster than females in the south and central delta, but not in other areas. Lack of an adequate forage base for larger fish and high population densities may be responsible for slow growth. While angling regulations have been changed to increase harvest and, potentially, reduce density, meaningful increases in catch would probably require changes in allowable fishing gear that may adversely impact other species.

INTRODUCTION

I report the age structure, growth, and length-weight relationship of white catfish, *Ameiurus catus*, in the Sacramento-San Joaquin Delta from specimens collected in 1978. A previous study of white catfish in the delta and Sacramento River during 1953-1954 (Borgeson and McCammon 1967) used only fish captured from the Sacramento River above the delta for growth rate estimates. My study provides the first information on growth of white catfish in the Sacramento-San Joaquin Delta and compares growth in the delta with that of other white catfish populations. Schaffter and Kohlhorst (1997) present a brief history of white catfish in the delta and describe mortality rates and the environmental setting.

METHODS

White catfish for this study were a 10% subsample of fish captured in hoop nets at 10 delta locations (Fig. 1) from October 1978 to January 1979 (after the growing season) as part of a tagging program (Schaffter and Kohlhorst 1997). Although only white catfish ≥180 mm fork length (FL) were tagged, trapped fish of all sizes were retained in the subsample for age and growth analysis. However, because not all fish <180 mm FL caught during tagging were measured, estimated length-frequency and age-frequency distributions of delta populations include only fish ≥180 mm FL.

In the laboratory, fish from the subsample were sexed, weighed to the nearest gram, and measured to the nearest millimeter fork length. The fifth spinal vertebra was excised for age estimation (Marzoff 1955).

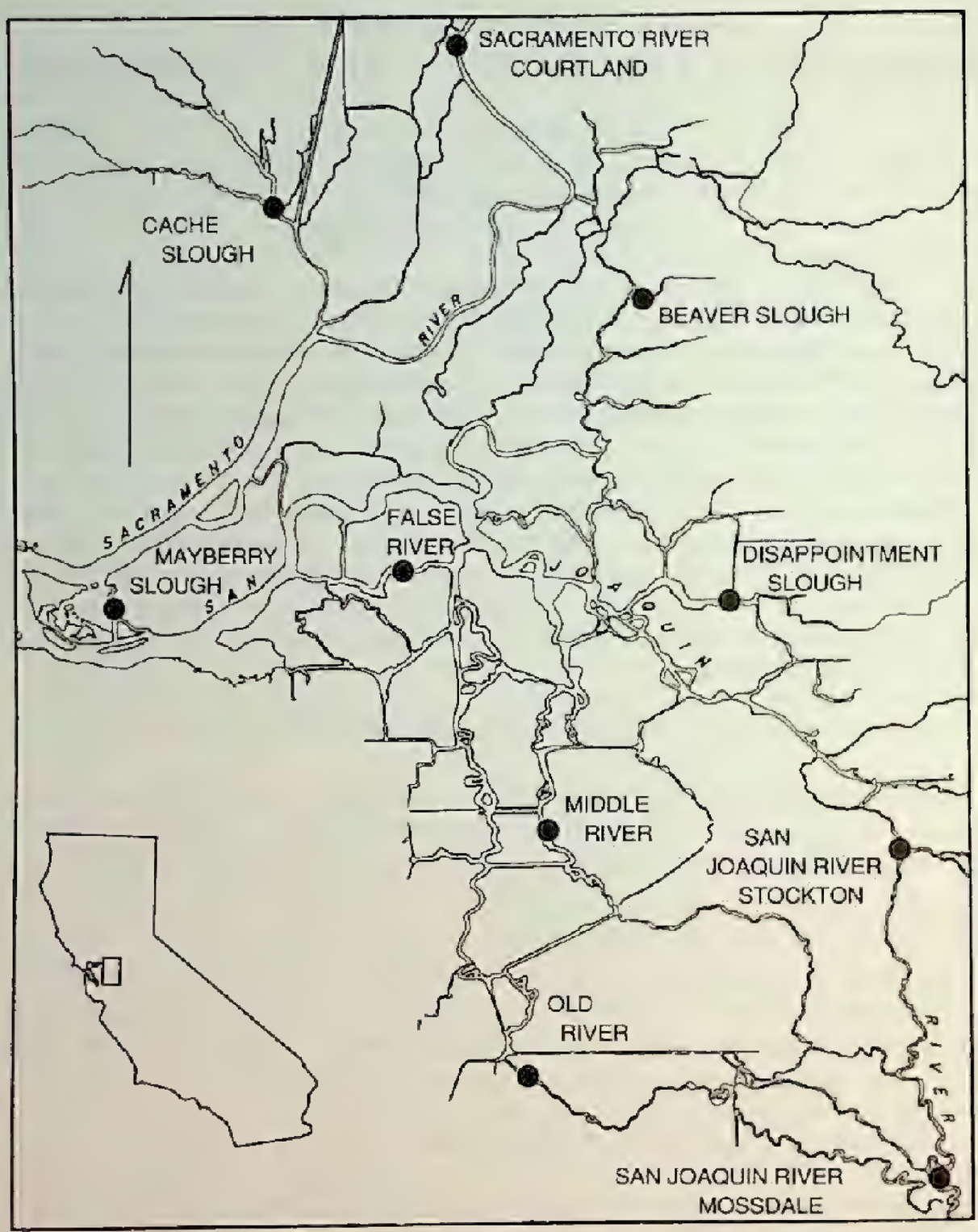

Figure 1. Locations in the Sacramento-San Joaquin Delta where white catfish were collected for the growth study in 1978.

Cleaned vertebrae were aged by counting translucent rings under a binocular microscope at 20x magnification. Mineral oil applied to the vertebrae enhanced contrast between translucent rings and opaque bands. To back-calculate length at annulus formation, an ocular micrometer was used to measure distance from the focus of the centrum to each annulus along a radius 45° dorsal to the lateral plane on the right anterior face of each vertebra. To be considered a true annulus, a translucent ring on the vertebra had to be complete (Marzoff 1955).

Two readers aged each fish and a third reader resolved differences. If two of the three readers could not agree on age, the fish was omitted from the analysis. Fish with lengths more than two standard deviations from the mean for that age were also deleted.

Fork length at age was back-calculated for each fish by the Frazier-Lee method (Carlander 1982), where:

$$L_i = a + \frac{(L_c - a)S_i}{S_c}$$

and L_i = calculated length at age i,
L_c = length at capture,
S_i = radius of annulus corresponding to age i,
S_c = total radius of vertebra at capture, and
a = 80.17 = intercept of the linear geometric mean (GM) functional regression of fork length on vertebral radius (FL = 80.17 + 64.4 vertebral radius, $r^2 = 0.83$, $P < 0.01$).

Geometric mean functional regression was used because both vertebral radius and length are subject to natural variation (Ricker 1973).

Growth estimates for catfish were stratified by grouping sampling locations. This stratification used K-means clustering of cases (Engleman and Hartigan 1988) based on similarity of back-calculated lengths at age and annual growth increment (length at age_{i+1} – length at age_i) for ages 2-6. Clustering was restricted to two groups to avoid clusters with sample sizes too small for reliable growth estimation.

Growth was described by the linear relationship:

$$l = a + b \ln(t)$$

where l = back-calculated length at last annulus, and
t = age in years.

The length-weight relationship was computed as the GM functional regression:

$$\ln(\text{weight in grams}) = a + b \ln(\text{length in millimeters}).$$

A Student's t-test for comparison of slopes of the growth regressions (Steele and Torrie 1960) was used to test for differences in growth between regional delta subpopulations identified by cluster analysis and between sexes.

RESULTS

A total of 2,070 white catfish was sampled for age and growth estimation. After deleting fish for which ages were unresolved or whose length at age was more than two standard deviations from the mean for that age, 1,810 fish remained for analysis.

Cluster analysis separated white catfish in the delta into two groups based on growth characteristics ($P < 0.01$). Fish from the north and west delta group

(Sacramento River, Beaver Slough, and Mayberry Slough; 327 aged fish) tended to be larger ($\chi^2 = 2,497$, df = 22, $P < 0.001$) (Fig. 2) and older ($\chi^2 = 1,092$, df = 10, $P < 0.001$) (Fig. 3) than fish from the south and central delta group (1,483 aged fish). The latter group includes fish from Cache Slough, which match the other members of the group in growth characteristics, but not location, because Cache Slough is in the northwest delta (Fig. 1).

Growth rates of white catfish, based on back-calculated lengths, were similar throughout the delta for the first 2 yr of life; after age 2, south and central delta fish grew slower than those of the north and west delta ($t = 7.35$, df = 1,806, $P < 0.01$) (Tables 1, 2, and 3). From age 4 on, males in both areas were larger than females; however, based on comparison of regression slopes, this difference was significant only in the south and central delta ($t = 2.24$, df = 1,479, $P < 0.05$).

The length-weight relationship for Sacramento-San Joaquin white catfish is:

$\ln(\text{weight}) = -12.283 + 3.193 \ln(\text{FL})$, with $r^2 = 0.966$ and $P < 0.001$.

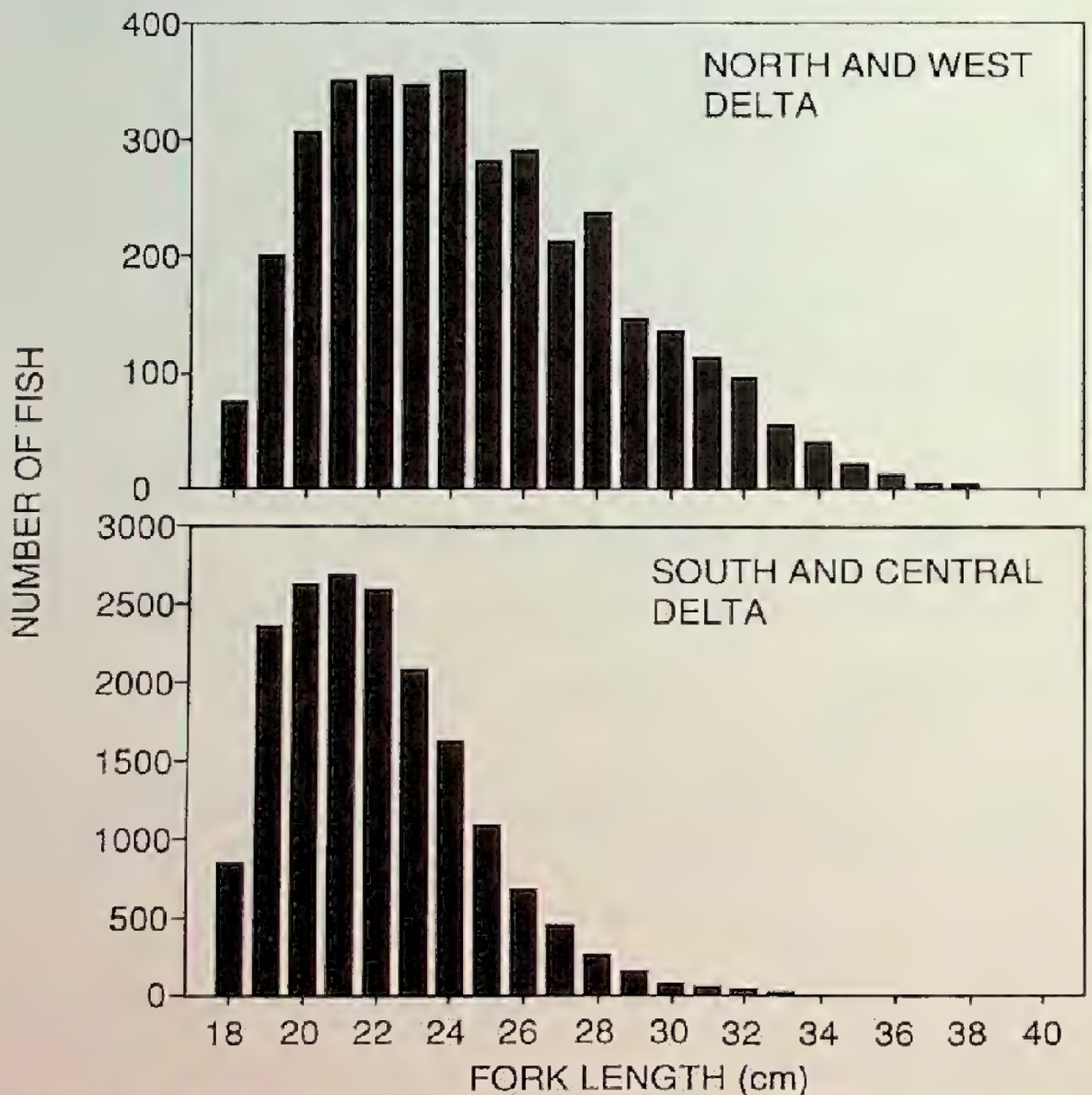

Figure 2. Length frequencies of white catfish tagged in 1978 in the north and west and the south and central Sacramento-San Joaquin Delta.

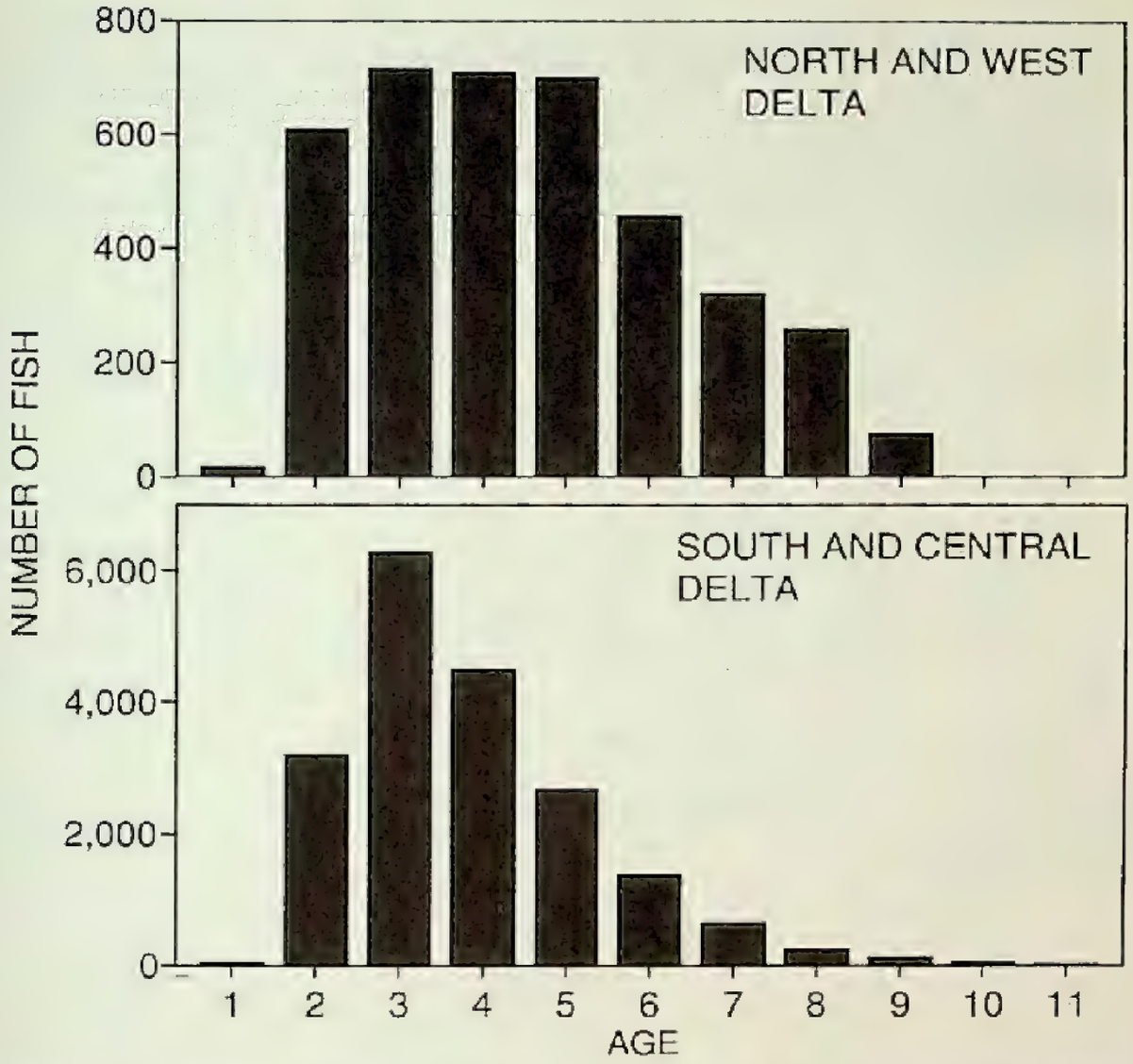

Figure 3. Estimated age composition of white catfish tagged in 1978 in the north and west and the south and central Sacramento-San Joaquin Delta.

DISCUSSION

In both groups, but particularly in the south and central delta group after age 1, mean back-calculated lengths through age 8 at a given age tended to decrease as capture age increased (Tables 1 and 2). This tendency, known as Lee's phenomenon (Ricker 1975), probably results from greater mortality of fast-growing fish so that the proportion of slow-growing fish increases in older age classes. The greater mortality experienced by larger, faster-growing fish may be partially explained by size-selective fishing mortality (Schaffter and Kohlhorst 1997). Bias due to Lee's phenomenon in comparisons of growth rates between sexes and areas was avoided by only using length at last annulus formation to calculate the relationship between length and ln(age) (Vaughan and Burton 1994).

Through age 3, lengths of white catfish from the Sacramento-San Joaquin Delta were similar to several other white catfish populations (Table 4). After age 3, white catfish from the delta were consistently small relative to white catfish elsewhere, except that north and west delta white catfish were larger than those from the Patuxent

Table 1. Back-calculated and observed fork lengths (mm) of white catfish collected in the north and west Sacramento-San Joaquin Delta in 1978. Only ages 1 through 8 are included because sample sizes at older ages were too small for reliable estimates. Fish were collected at the end of the growing season in the late fall and early winter, so they were essentially the same size as they would be the following spring at the time of annulus formation. Therefore, to facilitate comparisons with back-calculated lengths, observed lengths are entered in the table at vertebral ages 1 yr older than age at capture.

		Age							
Capture age	N	1	2	3	4	5	6	7	8
1	7	117.4							
2	64	111.9	158.0						
3	60	111.5	148.7	190.0					
4	57	112.5	150.6	184.2	210.8				
5	55	114.0	150.8	184.3	212.5	234.4			
6	35	114.9	149.5	181.6	212.5	236.1	255.7		
7	27	113.3	146.5	180.4	205.4	227.0	246.7	264.8	
8	16	111.8	144.7	180.1	206.6	233.0	250.6	266.7	283.5
Mean back-calculated length		112.9	151.0	184.3	210.4	233.2	251.6	265.5	283.5
Mean observed length at capture			165.3	189.4	208.0	225.1	247.5	265.4	279.7
Annual back-calculated growth increment			38.1	33.3	26.1	22.8	18.4	13.9	18.0
Males									
Back-calculated length		113.3	151.2	185.5	213.4	237.6	256.9	267.6	296.6
Females									
Back-calculated length		112.3	150.8	183.1	207.5	228.0	243.9	261.9	270.4

River until age 7. However, over all ages, Sacramento-San Joaquin Delta white catfish grow more slowly than other populations (Table 4); the slope of the regression on ln(mean total length) on age was lowest for fish from the delta. They grew at less than half the rate of the fastest-growing population (Alabama farm pond, slope = 200).

The small size of white catfish in the delta was recognized during Kimsey's[1] (1955) 1953-1954 studies and attributed to overharvest by the commercial fishery that had expanded rapidly during the 1940s (Warner 1949). A comparison of size distributions of fish captured at matching locations during 1953-54 and 1978 (Fig. 4) suggests that the commercial fishery had harvested a substantial fraction of the population larger than the commercial size limit of 212 mm FL. Legislation banned commercial fishing for catfish in the Sacramento-San Joaquin Delta in 1953. Notably, after age

[1] Kimsey, J.B. 1955. Quarterly narrative report for investigations projects, Project F-2-R-5, October 5, 1955. Inland Fisheries Division, California Department of Fish and Game, Sacramento, California, USA.

Table 2. Back-calculated and observed fork lengths (mm) of white catfish collected in the south and central Sacramento-San Joaquin Delta in 1978. Only ages 1 through 8 are included because sample sizes at older ages were too small for reliable estimates. Fish were collected at the end of the growing season in the late fall and early winter, so they were essentially the same size as they would be the following spring at the time of annulus formation. Therefore, to facilitate comparisons with back-calculated lengths, observed lengths are entered in the table at vertebral ages 1 year older than age at capture.

		Age							
Capture age	N	1	2	3	4	5	6	7	8
1	19	108.8							
2	302	113.9	152.8						
3	483	112.3	148.9	179.8					
4	327	113.7	148.2	177.6	201.4				
5	186	113.1	145.7	172.9	195.9	215.5			
6	93	111.9	142.3	169.9	190.4	207.6	224.7		
7	43	112.3	145.1	171.7	191.4	208.6	224.9	240.3	
8	17	108.7	139.5	162.9	187.4	203.6	222.3	237.5	252.7
Mean back-calculated length		112.9	148.5	176.7	197.3	211.8	224.5	239.5	252.7
Mean observed length at capture			148.7	189.3	206.4	222.4	235.3	242.8	255.7
Annual back-calculated growth increment			35.6	28.2	20.6	14.5	12.7	15.0	13.2
Males									
Back-calculated length		112.9	149.5	177.6	198.6	214.5	228.6	251.0	263.3
Females									
Back-calculated length		113.0	146.7	175.6	195.2	207.9	219.6	230.7	236.3

4, growth rates described by Borgeson and McCammon (1967) were greater than I found and were more similar to other populations, perhaps reflecting that they only aged fish from the Sacramento River, 50 km upstream of the delta, where population densities were relatively low (Warner 1949).

Turner (1966) suggested that the small size of Sacramento-San Joaquin Delta white catfish may reflect the unavailability of suitable forage fishes or effects of high turbidity on the ability of white catfish to capture piscine prey. Fishes made up only 41% of the food volume of Sacramento-San Joaquin Delta white catfish in 1963-1964 (Turner 1966) compared to more than 90% in the fast-growing Clear Lake, California population (Kimsey[2] 1954).

Intraspecific competition may limit growth in the delta. In the south and central delta, where white catfish growth was slower, population densities, as suggested by

[2] Kimsey, J.B. 1954. Quarterly narrative report for investigations projects, Project F-2-R-4, October 8, 1954. Inland Fisheries Division, California Department of Fish and Game, Sacramento, California, USA.

Table 3. Coefficients of the regression equation for the back-calculated length-at-age relationship fork length = a + b ln(age) of Sacramento-San Joaquin Delta white catfish, stratified by location and sex.

Location	Sex	Coefficients a	b	N	r^2
North and west delta	Males	96.8	89.1	175	0.90
	Females	100.3	80.7	152	0.87
	Combined	97.7	85.6	327	0.89
South and central delta	Males	102.7	71.7	743	0.87
	Females	106.0	67.7	740	0.87
	Combined	104.4	69.3	1,483	0.86

Table 4. Comparison of back-calculated total lengths (mm) at age of white catfish in the Sacramento-San Joaquin Delta in 1978 with total lengths from other locations. For this comparison, fork lengths from all California studies have been converted to total length by the regression TL = 6.78 + 1.05 FL derived from delta white catfish during this study. Table modified from Hughes and Carlson (1986).

Location	N	Age 1	2	3	4	5	6	7	8	Growth Rate[a]
South and central delta	1,248	125	163	192	214	229	243	258	272	70
North and west delta	544	125	165	200	228	252	271	286	304	87
Patuxent River, Maryland[b]	470	116	150	185	211	243	266	300	338	103
Sacramento River[c]	463	89	145	191	231	271	313	351	375	140
Hudson River, New York[d]	80	94	150	213	265	307	339	364	369	144
Clear Lake, California[e]	93	119	183	244	297	343	372	396	407	148
Santee-Cooper Res., South Carolina[f]	179	81	137	206	272	325	366	399	437	178
Alabama farm pond[g]	167	119	330	358	419	452				200

[a] Growth rate = slope of the regression of total length (mm) on ln(age) (from table)

[b] Schwartz and Jackowski 1965

[c] Borgeson and McCammon 1967

[d] Hughes and Carlson 1986

[e] Kimsey, J.B. 1956. Quarterly narrative report for investigations projects, Project F-2-R-5, July 10, 1956. Inland Fisheries Division, California Department of Fish and Game, Sacramento, California, USA.

[f] Stevens 1959

[g] Elrod 1971 (length at end of growing season)

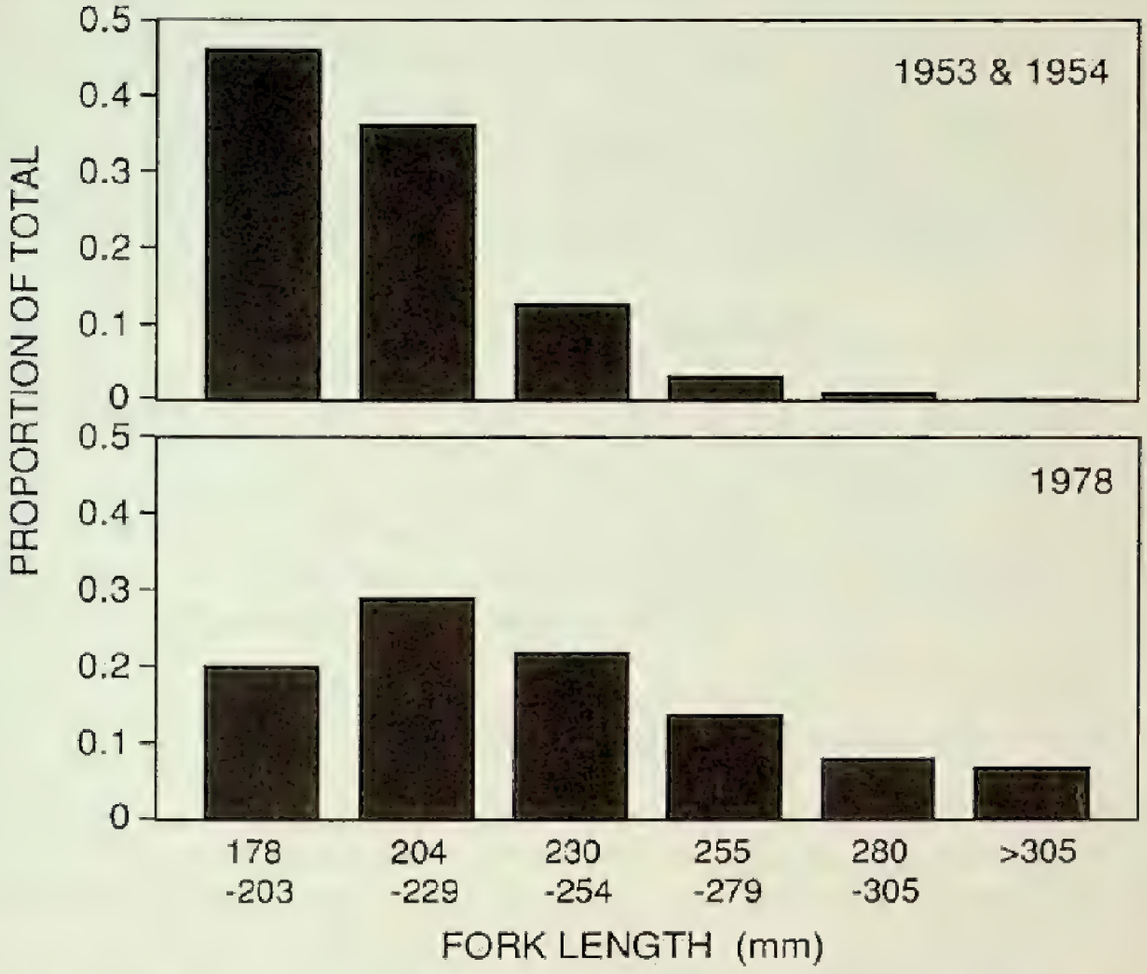

Figure 4. Length frequencies of white catfish at locations (Cache Slough, Mayberry Slough, Disappointment Slough, and Old River) where fish were captured both in 1953-1954 (Borgeson and McCammon 1967) and in 1978. Catfish from 1978 have been weighted by location to correspond to the 1953-1954 distribution.

fyke-net catch-per-unit-effort (CPUE) (1.18 fish/hoop-net-h during 1978) were greater than in the north and west delta (0.35 fish/hoop-net-h) (Schaffter and Kohlhorst 1997). The relatively high CPUE during 1978 of 0.61 fish/hoop-net-h at Cache Slough in 1978 (Schaffter and Kohlhorst 1997) may also partially explain why fish from that tagging site grew at rates similar to south and central delta samples.

Federal and State water diversions, increasing from 500,000 to 3.5 million cubic dekameters annually between 1953 and 1978 (California Dept. of Water Resources 1986), substantially changed water quality and flow conditions in the delta between the first delta catfish study in 1953-1954 and my study (Chadwick et al. 1977). However, since earlier growth studies were based on fish collected north of the delta, the impact of this water development on white catfish growth cannot be assessed. Changes in white catfish size distribution between 1953 and 1978 more likely resulted from reduction in exploitation associated with the cessation of commercial fishing and lower angling mortality (Schaffter and Kohlhorst 1997).

My results suggest that high population densities, coupled with reported low prey availability, may restrict growth of Sacramento-San Joaquin Delta white catfish. Exploitation of this population is not excessive (Schaffter and Kohlhorst 1997);

greater harvest potentially could reduce abundance, especially in the south and central delta, and increase growth. Based in part on these findings, effective 1 March 1987, the California Fish and Game Commission eliminated the creel limit of 20 catfish that had been applicable to the delta. Although this action may not have substantially increased legal harvest because few anglers catch as many as 20 catfish/d (Wixom et al.[3] 1995), other options, such as allowing the use of more efficient fishing gear (set lines, traps, or nets), are incompatible with efforts to maintain other delta fisheries.

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DEMOGRAPHY OF MOUNTAIN SHEEP IN THE EAST CHOCOLATE MOUNTAINS, CALIFORNIA

NANCY G. ANDREW[1]
Department of Natural Resources Science
University of Rhode Island
Kingston, Rhode Island 02881

VERNON C. BLEICH
California Department of Fish and Game
407 West Line Street
Bishop, California 93514

PETER V. AUGUST
Department of Natural Resources Science
University of Rhode Island
Kingston, Rhode Island 02881

STEVEN G. TORRES
California Department of Fish and Game
1416 Ninth Street
Sacramento, California 95814

We estimated the total population size and sex and age ratios of mountain sheep, *Ovis canadensis nelsoni*, in the East Chocolate Mountains, Imperial County, California during 1992-1993. We collected data using ground observations, remote cameras, and helicopter surveys. Mark-recapture population estimates were based on 17 females and 8 males that had been fitted with radio collars. Of the three methods, only helicopter surveys met the assumptions inherent in mark-recapture sampling methodology. Based on helicopter surveys, we estimated that 160 animals inhabited the study area during 1993, with a 95% confidence interval of 138-203 individuals. The adult sex ratio was 74 males:100 females. Yearling ratios (13:100 females), fall lamb ratios (38:100 females) and high annual adult survivorship (0.95) suggest that the population increased during 1993.

INTRODUCTION

Mountain sheep, *Ovis canadensis*, once were widespread in California; by 1940, however, 45 of 108 known populations had been extirpated (Wehausen et al. 1987, Bleich et al. 1990a). In an effort to curb their decline, California legislated total protection of wild sheep in 1873, but this action did not prevent further declines. Population assessment and water development projects were initiated in the

[1] Present address: California Department of Fish and Game, P.O. Box 1347, Brawley, California 92227.

mid-1950s, but the first formal report on the status of mountain sheep in the East Chocolate Mountains did not become available until 1969, when Weaver and Mensch[2] (1969) reported that 25-40 mountain sheep occurred in that range. Their estimate was based on anecdotal accounts and limited ground work. Given the difficulty of estimating the number of unmarked animals over a large geographic area, the accuracy of this early population estimate is suspect.

Current efforts to conserve this species by the California Department of Fish and Game (CDFG) include determining the distribution and demographic status of remaining populations, undertaking habitat improvements in mountain ranges occupied by wild sheep, and re-establishing sheep populations in areas that they previously occupied (Bleich and Torres 1993). Because the population of mountain sheep occupying the East Chocolate Mountains represents a potential source of reintroduction stock within the Sonoran Desert metapopulation (Torres et al. 1994, 1996), surveys were initiated in 1992 to more rigorously evaluate the status of this population. During 1992-1993, we carried out a study to estimate the total size, sex and age structure, and survivorship of this population, and to determine the efficacy of several population survey techniques. One of our goals was to establish a population monitoring protocol for this large, remote desert region.

STUDY AREA

The Chocolate Mountains are located in southeastern California (Fig. 1); California Highway 78 bisects the range and forms the western boundary of our study area. Mountainous areas west of the highway are managed by the U.S. Department of Defense and are used as an aerial gunnery range. The Colorado River forms the 50-km eastern boundary of the study area and affects mountain sheep distribution and movements. The study area is bounded on the north by Milpitas Wash and on the south by the All American Canal. This region (900 km^2) is characterized by several low-elevation mountainous areas that are separated by broad desert washes; the highest elevation in the study area is 647 m. Mountain ranges within 20 km of the study area, and of possible significance to this population of sheep (Bleich et al. 1990a), include the West Chocolate, Cargo Muchacho, and Palo Verde mountains. The study area is centered (33°07'N, 114°53'W) approximately 75 km east of the town of Brawley, Imperial County.

The climate is characterized by extreme aridity and high summer temperatures (Loeltz et al. 1975, Turner and Brown 1982). From 1983 to 1992, the average annual rainfall was 6.35 cm, which fell during two distinct rainy seasons in late summer and in winter (Andrew[3] 1994). Late summer thunderstorms often are localized and areas

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[2] Weaver, R.A. and J.L. Mensch. 1969. A report on desert bighorn sheep in eastern Imperial County, California. California Department of Fish and Game, Federal Aid in Wildlife Restoration Report W-51-R-14. Sacramento, California, USA.

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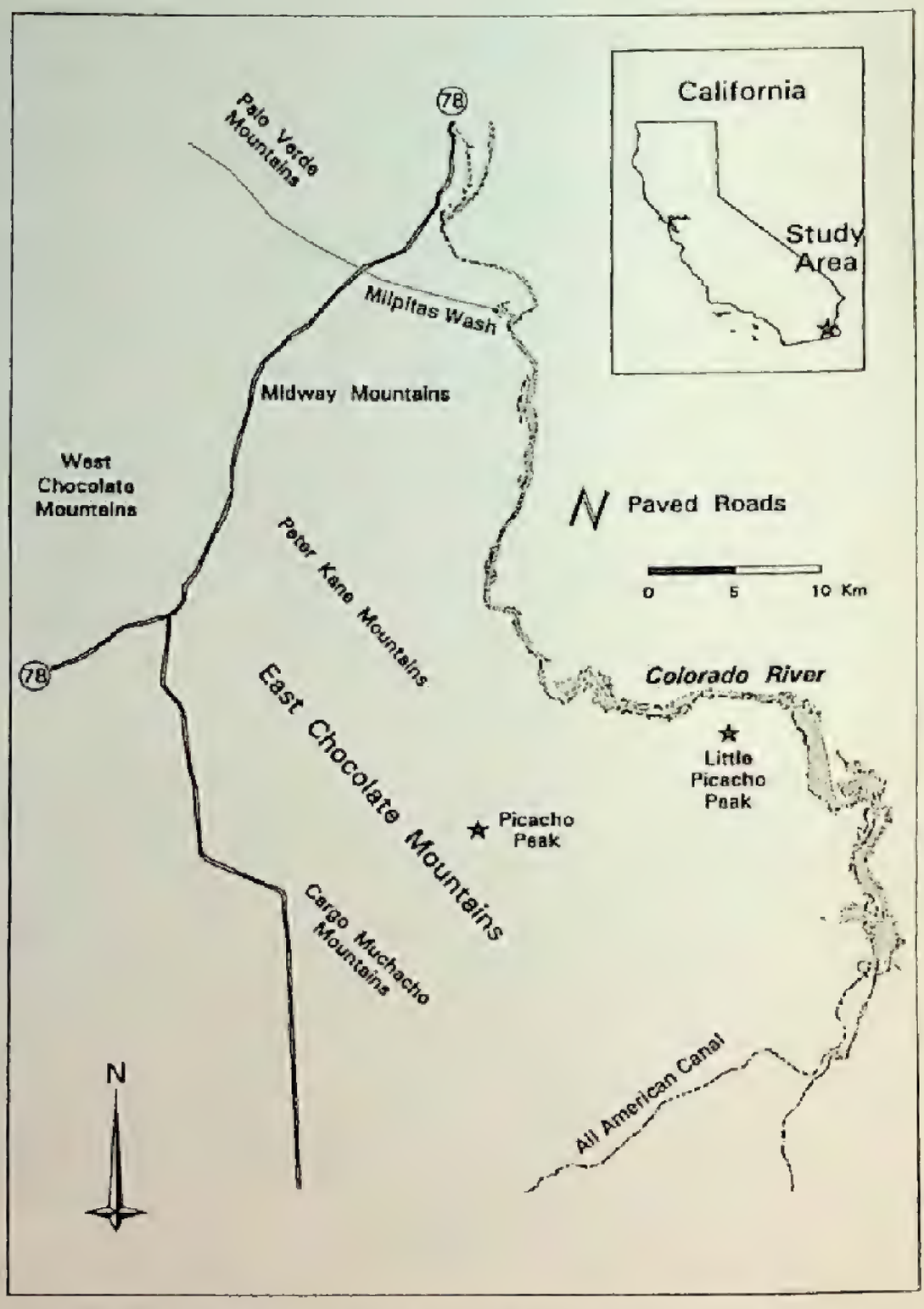

Figure 1. The East Chocolate Mountains are located in Imperial County, California, adjacent to the Colorado River.

adjacent to the Colorado River receive more precipitation than areas farther to the west (Weaver and Mensch[2] 1969). From 1983 to 1992, summer maximum temperatures routinely exceeded 40°C and annual winter minima often approached 0°C (Andrew[3] 1994).

Mule deer, *Odocoileus hemionus*, and feral asses, *Equus asinus*, are ungulates that are sympatric with mountain sheep throughout the Chocolate Mountains. Mule

deer occur at very low densities (Thompson and Bleich 1993), but feral asses exceed (N.G. Andrew, unpubl. data) the management objective of 66 total animals established by the USDI Bureau of Land Management (BLM). Currently, no forage is allocated for livestock in the study area, but cattle grazing occurred prior to 1970 (K. Schwartz, BLM, pers. comm.). In the East Chocolate Mountains, potential predators of mountain sheep (Kelly 1980) include mountain lion, *Puma concolor*; bobcat, *Lynx rufus*; coyote, *Canis latrans*; and golden eagle, *Aquila chrysaetos*. Neither the population densities nor the effect of these predators on mountain sheep in the East Chocolate Mountains are known.

METHODS

We captured 25 mountain sheep (17 females and 8 males) in June 1992, using a hand-held net-gun fired from a Bell 206B-III helicopter (Krausman et al. 1985); these sheep were captured throughout the study area to ensure an even distribution of the telemetry collars. We estimated sheep ages (Andrew[3] 1994) using tooth replacement (Deming 1952) and growth rings on horns (Geist 1966). We collected biological samples (whole blood, nasal and ear swabs, and ectoparasites) for other investigators prior to fitting each sheep with a radio-collar (Bleich et al. 1990b) equipped with a mortality sensor (6-h delay; Model 500, Telonics, Inc., Mesa, Arizona, USA). We also placed one plastic tag in each ear; together, these tags provided unique number and color combinations, allowing us to readily identify individuals. Telemetered animals served as "marked" individuals throughout the investigation.

We collected demographic data during the summers of 1992 and 1993 using direct observations, remote cameras, and helicopter surveys, with the goal of combining data sets to increase sample size (Jaeger et al. 1991) and, hence, the precision of our estimates. We classified each sheep observed as class I (yearling), II, III, or IV males; yearling females; adult females (age $\geq$ 2 yr); or lambs (individuals of either sex $<$ 1 yr old) (Geist 1968). We made direct observations on a scheduled basis, either from a vehicle or on foot. The study area was partitioned into six ground survey blocks (Norton-Griffiths 1978) and we sampled each in rotation. Generally, 1-3 d effort was required to sample each survey block. Approximately 300 and 400 h were spent in sheep habitat conducting ground surveys during the summers of 1992 and 1993, respectively.

We used time-lapse Super-8 movie cameras (Jaeger et al. 1991) and 8-mm video cameras to record sheep at 14 water sources during 1992 and 1993. Time-lapse cameras recorded one frame/min during daylight hours (Davis and Bleich 1980); video cameras recorded data for 3 consecutive min after being triggered. Video cameras could be reactivated every 3 min.

Aerial survey blocks (Norton-Griffiths 1978) were delineated prior to the June 1993 survey, based upon the known distribution of female sheep determined from 1 yr (June 1992 through May 1993) of aerial telemetry data (Andrew[3] 1994); these survey blocks remained unchanged thereafter. We assumed that our sample of marked sheep was representative of known ewe subgroups and that their distribution

represented the core areas of use. This assumption was reasonable in that all of the known water sources were included in the survey blocks and mountain sheep concentrate near water sources during summer (Blong and Pollard 1965).

During 1993, we conducted helicopter surveys in June (8.4 h) and September (10.4 h). Immediately before each helicopter survey, we used fixed-wing aerial telemetry to confirm the number of marked animals in each survey block. During the helicopter surveys, we employed a simultaneous double-count (Graham and Bell 1989) so that the competitive nature of participants increased observer attention.

We estimated the population of mountain sheep ≥ age 1 using Chapman's (1954) unbiased estimator for data obtained during the June and September helicopter surveys. We considered each of these surveys to be sampling without replacement (Krebs 1989), as no marked animals were observed more than once. Population estimates based on ground or camera surveys were calculated using Bailey's (1952) modification of Lincoln's (1930) method, which assumes sampling with replacement. We tested for equal catchability of marked animals between sampling methods using the Zero-Truncated Poisson Test (Caughley 1977). To increase sample size for generating more precise population estimates from the helicopter survey data, we pooled data and used Bailey's (1952) estimator after testing for and determining that there was equal catchability .

We calculated 95% confidence intervals for the population estimators (Seber 1982) and sex and age-class ratios (Zar 1984) for each survey method. Aerial telemetry data revealed the presence of two female demes (subpopulations [Andrew[3] 1994]); therefore, we derived separate population estimates for each method, year, and deme. Because of the small number of marked males, and because some of these males moved between the northern and southern areas (Andrew[3] 1994), we calculated male abundance for the entire study area. We pooled all females ≥ 1 yr old into a single category for calculating sex ratios and lamb ratios. We based yearling ratios on the number of adult (≥ age 2) females observed.

We estimated annual survivorship and associated 95% confidence intervals of adult radio-collared sheep using the method of Heisey and Fuller (1985). We rounded sampling intervals to the nearest 0.5 month, as all mortalities were known within a 2-week period.

RESULTS

Total population estimates varied from 149 (June 1993 helicopter survey) to 396 (1993 camera data) (Andrew[3] 1994). We determined, however, that neither the 1992 ground nor time-lapse camera data could be used to estimate demographic parameters, as sampling was not evenly distributed across the study area. This occurred because not all water sources available to sheep had been identified at that time. Similarly, we eliminated the 1993 camera data from further analysis.

Our tests of equal catchability indicated that the 1993 ground observations and the two 1993 helicopter surveys could be combined ($\chi^2 = 0.495$, df = 2, $P > 0.75$). Nevertheless, we did not do so because of our inability to sample evenly throughout the study area during the 1993 ground surveys. Using the June and September (1993)

helicopter data alone, we estimated the total population to be 149 and 189 in those 2 months. As expected, the population estimate of 160 with both surveys combined was more precise (95% CI = 138-203) than when either the June or September results were considered separately (Table 1).

Because of differential habitat use by male and female mountain sheep (Bleich et al. 1997) and our inability to sample from the ground with equal intensity among those habitats, we estimated age and sex ratios using only data obtained during aerial surveys. When sex ratios of adult animals derived from aerial observations during June (82 males:100 females) and September (68 males:100 females) were combined, an estimate of 74 males:100 females was obtained (Table 2). Yearling ratios showed little variation between survey periods, with a resulting estimate of 13 yearlings:100 females when data were pooled (Table 3). During June, the lamb

Table 1. Population estimates and 95% confidence intervals of the total (adult and yearling animals combined) mountain sheep population, northern and southern female demes, and of males, derived from aerial surveys using a helicopter in the East Chocolate Mountains, Imperial County, California, 1992-1993.

Date and type of sample	Population estimate	Lower CI	Upper CI
June 1993			
Total population	149	103	273
Female population	77	50	171
Northern deme	56	29	208
Southern deme	21	13	49
Male population	48	24	124
September 1993			
Total population	189	121	360
Female population	105	67	235
Northern deme	48	31	85
Southern deme	59	13	425
Male population	55	25	145
Combined aerial surveys			
Total population	160	138	203
Female population	97	80	135
Northern deme	61	59	73
Southern deme	36	13	84
Male population	49	28	118

Table 2. Sex ratios of mountain sheep (n males:100 females) derived from aerial surveys in the East Chocolate Mountains, Imperial County, California, 1993. Confidence intervals (95%) are for male ratios after they were standardized to 100 females.

Period	Males	Females	Ratio	95% CI
June	27	33	82:100	73-88
September	31	45	68:100	58-77
Combined	58	78	74:100	64-82

ratio was higher (44 lambs:100 females) than in September (38 lambs:100 females) (Table 3). It was not appropriate to combine these results because high mortality of lambs is likely during the summer (Welles and Welles 1961). Thus, lamb:female ratios would be expected to be lower during the fall survey.

Three radio-collared animals (two females and one male) died during this investigation; we estimated annual adult survivorship to be 0.95, with a 95% CI of 0.95-0.99. We were unable to confirm the cause of death of any animal that died, but no evidence of predation was detected.

DISCUSSION

Previous surveys (Weaver and Mensch[2] 1969; J.R. Thompson, CDFG, unpubl. data) yielded subjective population estimates ranging from 25 to 53 animals for the study area. Prior to our efforts, the most recent estimate was 25-40 animals (CDFG[4] 1989). Our data indicate that far more than 40 sheep inhabit the East Chocolate Mountains. We used several techniques in an effort to ascertain the best population estimate of this low-density, widely distributed mountain sheep population, with the goal of enhancing sample sizes for estimating demographic parameters. In the end, the time-lapse camera and ground observation data were not practical because of our inability to sample uniformly across a large geographic area with few access points. Helicopter survey was the only method that fulfilled the requirement of uniform sampling effort in our mark-recapture technique, despite successful efforts of other investigators to combine data from different survey methods (Jaeger et al. 1991). The helicopter survey conducted during June produced male:female and yearling:female ratios similar to those derived during September. However, combining the results of these surveys did little to improve the precision of the estimates. As expected, the lamb:female ratio declined between June and September so, as noted previously, it was not appropriate to combine these data.

Based on an intensive telemetry investigation, Andrew[3] (1994) identified two female demes in the study area; each inhabited rugged terrain isolated from the other

Table 3. Ratios of yearling and young (< 1 yr old) mountain sheep:100 adult females derived from helicopter surveys in the East Chocolate Mountains, Imperial County, California, 1993.

	Yearlings/100 adult females		Young/100 females ≥1 yr old	
Period	Estimate	95% CI	Estimate	95% CI
June	10	4-16	44	34-54
September	15	8-23	38	28-48
Combined	13	7-21		

[4] CDFG (California Department of Fish and Game). 1989. Bighorn sheep investigations from July 1, 1988 to June 30, 1989. California Department of Fish and Game, Federal Aid in Wildlife Restoration Project, Job Progress Report W-65-R-6, Study I, Job 4. Sacramento, California, USA.

by a desert flat ≥ 5 km wide that receives heavy human use. Although telemetered males moved between these areas, females did not (Andrew[3] 1994), and we assumed that movements of marked animals were representative of the behavior of male and female sheep in general. Female mountain sheep exhibit a high degree of philopatry and generally remain on the home range of their maternal group (Festa-Bianchet 1986). Hence, interchange of females between these demes probably occurs infrequently. The ratio of lambs to yearling and adult females (Table 4) suggests the potential for a general population increase during 1993, especially given the estimated high survivorship of adults. Nevertheless, the potential for independent dynamics of these female demes dictates that managers consider the implications of their actions on a localized basis (Stevens and Goodson 1993, Bleich et al. 1996).

Consideration of mountain sheep populations as metapopulations emphasizes the need for regional management to ensure long-term population viability (Schwartz et al. 1986; Bleich et al. 1990a, 1996; Torres et al. 1994, 1996). The East Chocolate Mountains population is an important part of the Sonoran Desert metapopulation (Torres et al. 1994, 1996). Continuous, long-term mark-recapture sampling using aerial surveys and telemetered animals should be implemented to better understand the population-level effects of environmental and demographic stochasticity in the East Chocolate Mountains (particularly given the presence of multiple female demes), and their potential effects on adjacent populations in the metapopulation.

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RANGE EXTENSION OF THE QUILLBACK ROCKFISH, *SEBASTES MALIGER*, TO THE SOUTHERN CALIFORNIA BIGHT

MILTON S. LOVE
Marine Science Institute
University of California
Santa Barbara, California 93106

ROBERT N. LEA
California Department of Fish and Game
20 Lower Ragsdale Drive
Monterey, California 93940

The quillback rockfish, *Sebastes maliger*, is a shallow to moderate depth species (rarely to 274 m) usually found on or near the bottom over high relief areas. Originally described from four specimens taken off San Francisco, California by Jordan and Gilbert (1880), *S. maliger* is the type species for the subgenus *Pteropodus*. Its geographic range was previously recorded as Gulf of Alaska to Avila, California and possibly south to Point Conception (Gotshall 1989). Here, we report on the capture of 17 quillback rockfish from central (Monterey and San Luis Obispo counties) and southern California. Three of the captures were from the Southern California Bight, one as far southeast as the Anacapa Passage (34°00'N, 119°30'W), a range extension of 195 km.

Quillback rockfish are abundant and commercially important from at least southeast Alaska to Puget Sound, Washington (Moulton[1] 1977, Kramer and O'Connell 1988, Murie et al. 1994). Richards (1986) and Matthews (1990) reported on depth and habitat preferences for quillback rockfish off British Columbia and Washington. There are no specific surveys of quillback rockfish populations off the coast of Oregon or California. However, data from the Marine Recreational Fisheries Statistical Survey (MRFSS) indicate quillback rockfish are rare south of San Francisco, California (Karpov et al. 1995) (Fig. 1); these observations are supported by Miller and Gotshall (1965). Quillback rockfish scarcity in central California, especially off San Luis Obispo County, is confirmed by sampling data of the California Department of Fish and Game's Central California Marine Sport Fish Project. In this study, from 1987 through 1992, only one quillback rockfish was noted out of 25,844 fishes sampled on commercial passenger fishing vessels from San Luis Obispo County

[1] Moulton, L.L. 1977. An ecological analysis of fishes inhabiting the rocky nearshore regions of northern Puget Sound, Washington. Ph.D. Dissertation, University of Washington, Seattle, Washington, USA.

80	81	82	83	84	85	86	AREAS
-	0	0	0.03	0.02	0.05	0	Northern Oregon
-	0.05	0.27	0.12	0.27	0.21	0.13	Central Oregon
0.06	0.14	0.95	0.03	0	0.27	0	Southern Oregon
0.10	0.05	0	0.18	0.26	0.34	0.37	Del Norte Humboldt
0.02	0.12	0.18	1.10	0.12	0.08	0.21	Mendocino Sonoma
0	0	0	0.10	0.05	0.04	0.12	San Francisco
0	0	0	0.04	0.04	0.03	0	Santa Cruz Monterey
0	0	0	0	0	0	0	San Luis Obispo
0	0	0	0	0	0	0	Santa Barbara Ventura
0	0	0	0	0	0	0	Los Angeles
0	0	0	0	0	0	0	Orange
0	0	0	0	0	0	0	San Diego

Figure 1. Percent of the total marine recreational fish catch contributed by quillback rockfish off Oregon and California from 1980 to 1986. California catch is stratified by county with the exception of San Francisco, which represents Marin, San Francisco, and San Mateo counties. Darker shading denotes higher quillback rockfish contribution to the catch. Data from the Marine Recreational Fisheries Statistical Survey (K. Karpov, California Department of Fish and Game, pers. comm.).

ports (Reilly et al.[2] 1993, Wilson et al.[3] 1996).

In addition to recent captures (since 1970) of quillback rockfish in Monterey and San Luis Obispo counties and the Southern California Bight (Table 1), five quillback

[2] Reilly, P.N., D. Wilson-Vandenberg, D.L. Watters, J.E. Hardwick, and D. Short. 1993. Onboard sampling of the rockfish and lingcod commercial passenger fishing vessel industry in northern and central California, May 1987 to December 1991. California Department of Fish and Game, Marine Resources Division Administrative Report No. 93-4.

[3] Wilson, C.E., L.A. Halko, D. Wilson-Vandenberg, and P.N. Reilly. 1996. Onboard sampling of the rockfish and lingcod commercial passenger fishing vessel industry in northern and central California, 1992. California Department of Fish and Game, Marine Resources Division Administrative Report No. 96-2.

Table 1. Capture localities for quillback rockfish in central and southern California (specimens examined for this study). We have included: fish length (total length), fishing mode, depth of capture (when known), and date of capture. CPFV refers to commercial passenger fishing vessel. Localities of capture are listed from north to south.

Monterey County
Monterey (landed; exact locality unknown), 39.0 cm, CPFV, 20 October 1983.
Point Pinos, 41.3 cm, CPFV, 8 November 1983.
Point Joe, CPFV, 29.2 cm, 71 m, 11 September 1995
Cypress Point, 20.4 cm, CPFV, 7 November 1983.
Cypress Point, 37.5 cm, CPFV, 5 December 1983.
Cypress Point, 39.0 cm, CPFV, 13 December 1983.
Sunset Point, 35.5 cm, CPFV, 82 m, 8 October 1987.
Point Lobos, 39.0 cm, CPFV, 10 November, 1980.
Yankee Point, 34.5 and 40.7 cm, research cruise, 16-55 m, 25 April 1979.
Point Sur, 27.0 cm, CPFV, 30 September 1984.
Point Sur, 36.5 cm, 109 m, commercial set-line, 8 March 1993.
Square Black Rock, 36.7 cm, commercial hook-and-line, 8 June 1983.
San Luis Obispo County
San Simeon, 26.3 cm, CPFV, 28 May 1977.
Southern California Bight
Richardson Rock, San Miguel Island, 37.7 cm, CPFV, 80-100 m, May 1995.
Richardson Rock, San Miguel Island, 41.7 cm, CPFV, 80-100 m, January 1996.
Anacapa Passage, 29.4 cm, CPFV, June 1980.

rockfish were observed in situ from the research submersible *DELTA* on 27-28 September 1994 off Point Sur in depths ranging from 81 to 85 m. These quillback rockfish were observed on rock bottom; three sites contained large boulders. The estimated size of the fish was 30 (one) to 40 (four) cm TL, as measured by fixed parallel laser beams (M. Yoklavich, NMFS, Pacific Fisheries Environmental Group; unpubl. data).

Specific identification of rockfishes, especially larval and juvenile stages, is often dependent on meristic characters. Because these collections were from the southern end of the species' range, meristic data are included for 13 specimens (Table 2). All of these counts were within the ranges listed by Phillips (1957), with the exception of a high count of 34 total gill rakers in one individual.

Although San Miguel Island lies in the Southern California Bight, the presence of a cold water species such as quillback rockfish at this locale is consistent with previous observations of the island's marine fauna. There are two zoogeographic provinces along California's mainland coast (Seapy and Littler 1980): the warm-temperate Californian in the south and the cooler Oregonian farther north, referred to as San Diego and Oregon Provinces by Briggs (1974). In general, the Point Conception - Point Arguello region (34°30'N) forms the boundary between the two provinces. However, because San Miguel Island is the westernmost of the northern Channel Islands and is bathed by the California Current, the island's fauna is similar to that of central California (Hubbs 1967, 1974; Cowen 1985;

Table 2. Meristic data for 13 quillback rockfish from central and southern California[a].

Character	Meristic value	n
Dorsal soft-rays	13	13
Anal soft-rays	6	7
	7	6
Pectoral rays - unbranched	8	17
	9	9
Pectoral rays - total	17	23
	18	3
Gill rakers - upper limb	8	2
	9	11
	10	13
Gill rakers - lower limb	20	2
	21	4
	22	7
	23	12
	24	1
Gill rakers - total	29	2
	30	1
	31	9
	32	7
	33	6
	34	1

[a] Eleven specimens from Monterey County, one from San Luis Obispo County, and one from the Southern California Bight.

Love et al. 1985). The unique position of San Miguel Island in the Southern California Bight is exemplified by its being the southernmost geographic boundary for five colder-water fish species: mosshead warbonnet, *Chirolophis nugator*; masked prickleback, *Ernogrammus walkeri*; sailfin sculpin, *Nautichthys oculofasciatus*; black rockfish, *Sebastes melanops*; and China rockfish, *S. nebulosus* (Eschmeyer et al. 1983, Follett and Powell 1988).

Using sliced sagittal otoliths, Love aged the two fish from San Miguel Island. The 37.7-cm individual, captured in May 1995 at age 14 yr, was a mature male weighing 1,099 g and was spawned during 1981. The other specimen, captured in January 1996, was an 11-yr-old mature female; it measured 41.7 cm, weighed 1,378 g, and was spawned in 1985. Off northern and central California, quillback rockfish are April-July spawners (Wyllie Echeverria 1987). Thus, the two San

Miguel quillback rockfish were most likely spawned in the spring or summer of 1981 and 1985. In both years, the California Current was relatively strong, or at least the northward El Niño-Southern Oscillation-related flow was weak (University of California, Scripps Institution of Oceanography [SIO], CalCOFI cruise data, 1984-1986; Bailey et al. 1995; D. Roemmich, SIO, pers. comm.). Because pelagic larvae of rockfishes may drift for several months, this condition would increase the chance of transport from a northern population to San Miguel Island and other northern Channel Islands, especially during these 2 yr.

It is likely that larval drift from central and perhaps northern California is the mechanism for transport of many of the cold-temperate species to San Miguel Island and the Southern California Bight. Movements of adult fishes to San Miguel Island must be very limited because the minimum depth between the island and the mainland is 385 m, deeper than the maximum depth for many of the colder-water species that inhabit San Miguel Island. Maximum larval transport would be expected to take place during years when the California Current is strongest.

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THE FIRST OCCURRENCE OF THE PANAMIC SERGEANT MAJOR, *ABUDEFDUF TROSCHELII* (POMACENTRIDAE), IN CALIFORNIA

DANIEL J. PONDELLA, II
Vantuna Research Group, Moore Laboratory of Zoology,
Occidental College
Los Angeles, California 90041

The Panamic sergeant major, *Abudefduf troschelii* (Gill, 1862), is one of the most common fishes in the Sea of Cortez (Thomson et al. 1979), where it is an important component of the nearshore rocky reef community. Previously collected as far north as Bahia San Juanico, Baja California (26°10.9'N, 112°21.8'W), the Panamic sergeant major is found as far south as Peru, including oceanic islands such as Cocos Island (UCLA W58-209), Revillagigedo Islands (Clarion-UCLA W51-285 and Socorro-UCLA W53-49) and the Galapagos Islands (Thomson et al. 1979, Allen and Robertson 1994). The Panamic sergeant major is easily identified by its distinctive five black vertical bars over a yellow back that fades to blue below the midline and a sixth black bar (less distinct) on the caudal peduncle (Fig. 1). Superficially, it can be confused with its congeners *A. saxatilis* in the Atlantic and *A. vaigiensis* from the Indo-West Pacific.

On 30 August 1996, while diving with J.S. Stephens, Jr. and K.B. Hartney, I observed two Panamic sergeant majors in King Harbor, Redondo Beach, California (33°50.5'N, 118°23.8'W) and captured one. The captured individual (Fig. 1) did not survive and consequently was fixed in 10% formalin and later preserved in 40% isopropyl alcohol for confirmation of the field identification, meristic counts, and measurements. Two individuals were also observed on 15 November and 19 December 1996 and one was seen on 17 December 1996 in the same location.

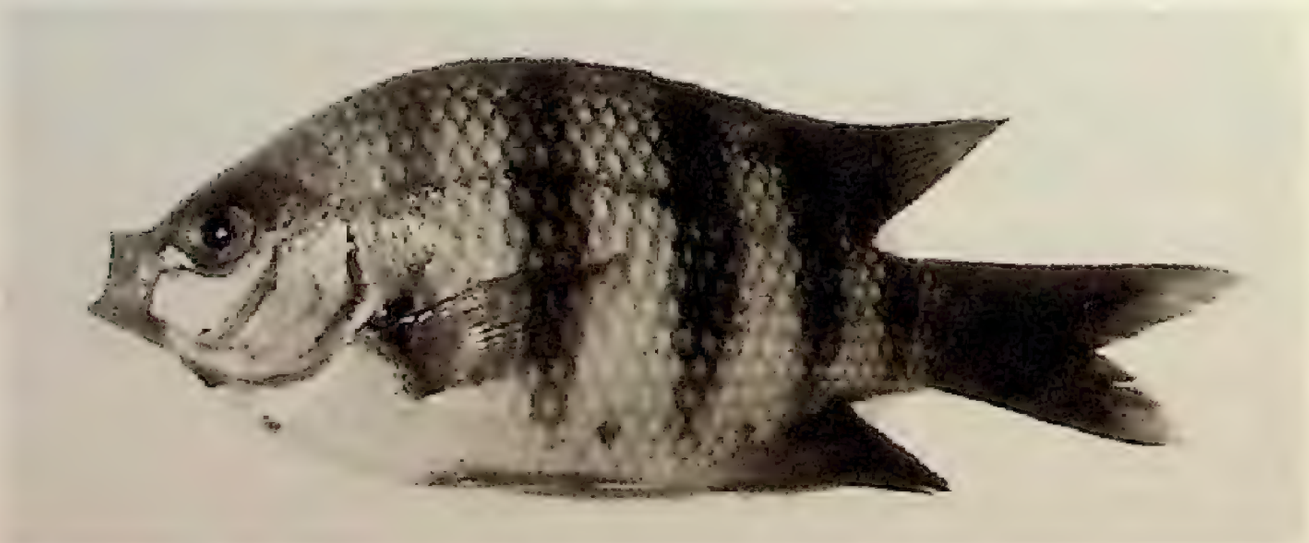

Figure 1. Left lateral view of the Panamic sergeant major, *Abudefduf troschelii*, (77.8 mm SL, SIO 97-50) captured in King Harbor, Redondo Beach, California on August 30, 1996. Photograph by Daniel J. Pondella, II.

However, we did not observe any on our extensive quarterly survey of King Harbor in September 1996. All individuals were observed on the interior of the outer breakwater within 1 m of the surface and were estimated to be 75-85 mm standard length. Water temperature on the transects where Panamic sergeant majors were observed was 22.0°C in August, 18.7°C in October, and 18.9°C and 18.6°C on 17 and 19 December. Counts and measurements (mm) of the captured specimen are: D XIII, 13; A II, 13; pect. (l) 16; gill rakers (l) 27; lateral line scales 23; standard length 77.8; total length 104.5; head length 24.2; snout length 7.6; upper jaw length 6.8; interocular distance 8.9; body depth 41.2; predorsal length 30.9; caudal peduncle length (dorsal) 8.4; caudal peduncle depth 12.8. It was deposited in the Scripps Institution of Oceanography (SIO 97-50). This collection represents a northern range extension of about 990 km.

Warm-water currents from the south, originating in El Nino Southern Oscillation events, may be the source of the Panamic sergeant major in King Harbor and of other warm-water fish in southern California (Radovich 1961, Mearns 1988, Stephens et al. 1989, Lea and Rosenblatt 1992, Lea and McAlary 1994, Lea and Walker 1995). However, it is unrealistic to believe that these small rocky reef fishes swam the entire coastline from Bahia San Juanico – perhaps they rafted on a drifting kelp patty. It is also possible that the aquarium trade or an inadvertent release from a bait well is the source of the Panamic sergeant major. However, it is unlikely that these fish were released intentionally, and there is no active sport fishing operation off southern Baja California based in King Harbor.

King Harbor is a haven for warm-water fishes. It is located in Santa Monica Bay, the most northern bay in the Southern California Bight offering refuge for warm-water species. Every year divers in King Harbor observe two resident serranids, the broomtail grouper, *Mycteroperca xenarcha*, and the spotted bay bass, *Paralabrax maculatofasciatus*. Both are warm-water species and the latter is not normally distributed north of Santa Monica Bay (Miller and Lea 1972, Eschmeyer et al. 1983, Allen et al. 1995). A range extension of the bluestriped chub, *Sectator ocyurus*, and the presence of the blue-bronze chub, *Kyphosus analogus*, both subtropical sea chubs (Kyphosidae), were also described in King Harbor (Brooks 1987). A resident population of zebraperch, *Hermosilla azurea* (Kyphosidae), has been found in King Harbor continually from 1974 to 1997, but zebraperch were rare north of the bight during this period and are not usually found above Santa Monica Bay (Eschmeyer et al. 1983, pers. obs.) Also, the only known location of the orangethroat pikeblenny, *Chaenopsis alepidota*, (Clinidae) on the mainland coast in the Southern California Bight is King Harbor (Stephens et al. 1989).

The temperature in King Harbor is above ambient due to the warm-water discharge of the Southern California Edison Redondo Beach Generating Station and the protection of the breakwaters (Stephens and Zerba 1981). This elevated temperature may attract and retain expatriated fishes when the bight cools (Brooks 1987).

King Harbor is the most extensively studied artificial reef in the world. Since 1974, the Vantuna Research Group has conducted 4,100 adult fish transects, 614 juvenile fish transects, and 417 cryptic reef collections in King Harbor as a part of an

ongoing study of its fish fauna. Rare fishes are likely to be found here due to the intensive monitoring of the harbor.

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BOOK REVIEW

A MANUAL OF CALIFORNIA VEGETATION by John O. Sawyer and Todd Keeler-Wolf. 1995. California Native Plant Society, Sacramento, California. 471 pages. $55.00 hard cover, $39.00 paperback.

California, like most states, has a legal mandate to protect its biotic resources. Recognizing that species conservation is costly relative to community or ecosystem conservation, and that conservation funds are limited, there has been a recent trend toward targeting larger ecological units (e.g., communities and ecosystems) for conservation. These large-scale efforts focus on developing a reserve system that includes representatives of all native plant and animal communities. If habitats, ecosystems, or communities are to be conserved, they must first be defined. Unfortunately, plant communities are difficult to distinguish objectively. Over the last 30 yr, ecologists in North America have posited that vegetation changes along environmental gradients in a continuum. The continuum concept in vegetation does not lend itself well to the conservation of biodiversity at the community level because it hinders discrete community definition. Identification of appropriate conservation units when communities lack sharp boundaries and readily distinguishing attributes poses a significant problem.

John Sawyer and Todd Keeler-Wolf have entered this problematic area with *A Manual of California Vegetation*, an outgrowth of a California Native Plant Society (CPNS) effort to develop a framework for vegetation classification that would allow uniform application of terminology among private groups and government agencies. The manual seems designed to streamline community conservation efforts in California by convincing all parties to adopt a single plant classification scheme that can be functionally applied.

However, the manual has already been challenged in content and methodology. At the Pacific Section of the American Association for the Advancement of Science meeting (San Jose, California, 1996), several vegetation scientists criticized the effort as classifying communities from the wrong end. *A Manual of California Vegetation* classifies vegetation units (called series) from the top down based on dominant vegetation, similar to the way that foresters classify timber stands. European vegetation ecologists (phytosociologists) prefer a bottom-up approach, basing classification schemes of floristic similarity, irrespective of the dominant canopy layer. Phytosociologists argue that top-down classifications do not represent ecological units. Further, these two camps prefer different data collection methodologies. This division between vegetation scientists runs deep and is likely to continue to create controversy over the appropriate approach to community classification.

Nonetheless, Sawyer and Keeler-Wolf's system has several advantages, including that i) previous classification schemes use a similar method, and thus this new system is easily cross-referenced to older systems and is familiar to field biologists; ii) the

database that supports this top-down classification scheme is easily expanded through the use of knowledgeable volunteers; and iii) remotely-sensed classification data, which are increasingly important in conservation efforts (e.g., the Gap Analysis Project) are readily cross-referenced to the Sawyer and Keeler-Wolf classification.

The basic unit used for describing vegetation by Sawyer and Keeler-Wolf is the series. A series is defined by a dominant, codominant, or characteristic species. Series are grouped by dominance of herbs (52 series), shrubs (107 series), or trees (81 series). Vegetation types that are not readily grouped by dominance are described as unique stand types (e.g., Monterey cypress stands), habitats (e.g., alpine habitat), or as vernal pool types (e.g., San Diego mesa vernal pools).

The layout and design of the book facilitates easy navigation through its 274 vegetation descriptions. Vegetation descriptions follow a standardized format containing i) a brief description of the dominant species, ii) location information (habitat, geographical distribution, and elevation), iii) a cross-reference to other vegetation classification systems, iv) general references, v) specific comments and descriptions, vi) a table listing species mentioned in the text, vii) references to plot-based descriptions, and viii) a list of plant associations recognized within the series. Series descriptions are clear and concise. The introduction contains a brief description of the process used to create this classification, a history of vegetation classification in California, a description of geographical regions of California, a description of how to use the book, a dichotomous key to help identify series, and color photos of many of the vegetation types. Additional supporting material includes an extensive bibliography; a thorough description of data collection protocols, including data forms; and separate indices to vegetation names, parallel classification system vegetation names, and plant names.

Time will tell whether the CNPS vegetation classification of Sawyer and Keeler-Wolf will unify vegetation classification in California. The team-building approach of CNPS and the clear methodology, thorough treatment of the subject, and effective presentation, give this effort an excellent chance for success. As such, *A Manual of California Vegetation* ought to be of interest to a wide array of ecologists in California.

— *Mark W. Schwartz*
Center for Population Biology
University of California
Davis, California 95616-8500

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